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# THE ORIGIN AND SYSTEMATICS OF FERRUGINOUS PRECIPITATES IN QUATERNARY FORMATIONS AND IN PRESENT-DAY SOILS

Sommaire

Les auteurs présentent une synthèse des résultats des recherches sur les conditions pédo-chimiques de la formation de diverses formes des précipités de fer et font la revue de la littérature du point de l'intérêt que de certaines branches des sciences de terre portent vers les possibilités que ces précipités offrent pour la détermination de la genèse et de la chronologie de certains phénomènes ayant lieu dans les formations quaternaires et les sols contemporains.

On présente aussi les résultats de nombreuses expériences de modelé (menées au laboratoire), où on a réussi à reconstituer de nombreuses formes des précipités de fer observées dans la nature. Cela permet d'éclaircir et de corriger les différences entre de divers points de vue sur la genèse et la signification stratigraphique de ces formes pour la recherche dans les sciences de Terre.

L'ouvrage se compose de chapitres suivants; l'introduction, la genèse des précipités de fer, les bases de la subdivision des précipités de fer, la caractéristique des formes et des variétés de précipités de fer, parmi lesquelles on a distinqué:

(a) non-concrétions — efflorescences: superficielles, de fentes, cellulaires; taches: concentriques, épanchées, infiltrations, en fentes-filets; pseudomycéliums; anneaux: verticaux, nids; bandes verticales: fentes, coins; cloisonnements: propres, perturbatives; bandes horizontales: cloisonnements, bandes homogènes, taches; niveaux: homogènes, taches, rouillures; cercles: propres, compliqués;

(b) concrétions — concrétions homogènes: poivres, pois, noisettes, nodules, minérais; concrétions crouteuses: tuyaux, ampoules, poires, boules; concrétions sphériques stratifiées: cylindres, doigts, poires, boules, chaines de boules; dalles: jointures, cannelures.

La possibilité de l'application des précipités de fer pour déterminer les rapports eau—air dans le sol.

Etablissement d'un tableau illustrant la genèse et la répartition des précipités de fer demande une subdivision de tous les sédiments à la base des conditions hydrologiques. On distinque donc les types suivants du milieu pédogénétique: A — sols secs, B — sols à humidité optimale. C — sols périodiquement trop humides, D — sols périodiquement humifères, E — sols perpétuellement humifères, F — sols périodiquement marécageux, G — sols des marécages, H — sols (vases) subaquatiques. Etant donné que la majorité des types du milieu pédogénétique énumérés

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produisent des familles déterminées de formes des précipités de fer on est capable de déchiffrer, d'après leur répartition, l'état des conditions d'humidité (type hydrologique) dans le passé.

## INTRODUCTION

The term *ferruginous precipitates* is here used to designate the totality of local concretions of tri- and divalent iron compounds. It is an overall term applying to all the forms of secondary concentrations of iron compounds and has, therefore, a much broader connotation than the well-known term *ferruginous concretions*, which it is, however, not intended to supplement or to modify. The introduction of the term *ferruginous precipitates* shows only that the actual state of research in this field has already outreached the study of *ferruginous concretions*. Since the origin of all kinds of ferruginous concretions must be investigated in close connection with non-concretional forms, such a new term had to be introduced. All the non-concretional forms represent the primary (initial) stages of the development of concretional ones. A systematization of ferruginous precipitates must therefore consider not only the morphology but also the genetic relationships between the individual units. A correct recognition of ferruginous precipitates provides a fairly adequate picture of the conditions prevailing within the ground in the time of their formation. This is due to the fact that the development of each particular form of ferruginous precipitates is chiefly controlled by a well-defined set of hydro-atmospheric conditions within the ground and a specific dynamics of the biochemical processes which characterize that set. Thus, a study of the origin of the particular forms of ferruginous precipitates must cover a much wider field than that of the pedochemistry of the iron itself, trying in the first place to consider the dynamics of oxidation within the ground environment. Both the system of air—water conditions and the dynamics of oxydation-reduction processes in the soil are subject to considerable fluctuations, whose amplitude and regularity depend on the physical properties of the ground. The dynamics of these processes are recorded by either the formation of corresponding ferruginous precipitates, or the absence of such precipitates within the soil. Since the present authors attribute a special significance — both theoretical and practical — to the study of ferruginous precipitates, they have attempted to systematize the units distinguished with regard to both their form and their origin.

## THE ORIGIN OF FERRUGINOUS PRECIPITATES

The origin of ferruginous precipitates and the possibility of using them as indicators of the sequence of modifications occurring within the ground environment is a problem that has frequently reappeared in the literatures of such branches of research as: soil science, geochemistry, hydrology, geology and geomorphology, mineralogy and petrology.

Certain forms of secondary concentrations of iron compounds such as for instance bog iron ores have already a long time ago aroused much interest, inspired by practical purposes. Many an early historical record mentions the occurrence and exploitation of bog iron ores in boggy regions. Much later, the sites and conditions of occurrence of bog iron ores became a subject of scientific descriptions and discussions. Owing to shrewed analyses of the natural conditions of such environments some of the conclusions reached in even the earliest of these scientific publications, have lost none of their value in the light of present-day knowledge. The natural conditions under which ferruginous precipitates are formed were already so thoroughly investigated in the last decades of the XIXth C. that Emeis (1875) was able to achieve a reconstruction of several forms in the laboratory.

The beginning of the XXth C. brought a number of further publications relating to the origin and the geographical distribution of certain forms of ferruginous precipitates. Outstanding among them were the works of such investigators as: Sukachev (1903), Glinka (1903), Vysockij (1905), Albert (1910), Frosterus (1913), Aarnio (1915), Afanaśev (1930), Bystrov (1936). Although these writers had at that time already, elucidated many a problem of detail in a way that hardly leaves any room for objections, their statements and assertions have up to now remained either ignored or disregarded. Hence the interpretations of the phenomena in question are still widely divergent.

Such divergences concerning the interpretation of the origin of ferruginous precipitates are found in practically each of the lines of research mentioned above, with geomorphology at the head. Next to geomorphology comes soil science though a notable progress has been here recently achieved. Such a state of the question is, besides, easily comprehensible since geomorphology in the first place and soil science in its trail still apply a method of individual i.e. static approach to the description of each single phenomenon.

Alone, a geochemical approach to the problem is apt to provide a sound knowledge and a correct stratigraphic interpretation of the various forms of ferruginous precipitates while the details may be elucidated through rigorous model (laboratory) experiments.

A discussion of the divergent views found in the literature on the origin and the stratigraphic significance of various forms of ferruginous precipitates will be preceded by a presentation of the view-point adopted by geochemists, hydrologists and soil-scientists.

The secondary migration and concentration of iron compounds which so often appear in the lithologic soil profile of both dry and swampy areas require the presence of water-dissolved compounds of divalent iron. Trivalent iron compounds are practically insoluble in water unless the pH of the solution drops below 3, a fact hardly ever occurring under the soil conditions of our country (Terlikowski, 1958). A larger amount of divalent iron in the soil-ground solution may be present only when the ground shows a definitely negative oxygen balance.

A negative oxygen balance within the ground environment although usually called forth by an excess of water is a direct effect of biochemical processes, the intensity of which — that entails an equivalent demand for oxygen — depends on the quantity and the activity of the organic matter. It is therefore easily comprehensible why the same quantity of organic matter may at a — theoretically — equal rate of biochemical modifications produce various oxydation-reduction effects. For these depend on the degree of ground-moisture that determines the rate of gas exchange between ground and atmosphere, thereby determining the quantity of oxygen supplied to the ground within a definite time unit. This regularity is most important and should be born in mind during any study of that phenomenon. In various discussions, doubts have been expressed as to whether a small quantity of organic matter may produce so intensive a reduction of the ground environment. Apart from the fact that the results obtained by the present writers through a whole number of laboratory experiments have definitely cleared this doubt (Siuta, 1960, 1962, 1966) it may be appropriate to quote the opinion of Książkiewicz who wrote in 1959: „Even a very small quantity of organic matter suffices to reduce iron oxides; provided the rock contains 20% of $Fe_2O_3$ or $Fe(OH)_3$, as little as $^1/_4$% of organic matter is apt to reduce this amount of iron to a black, tiny particled magnetite that gives the deposit a grayish colour". If the reductive processes are very intensive and the content of ferric hydroxides is rather negligible the entire quantity is rapidly converted to the divalent form. Thus the rusty brownish and insoluble iron compounds pass into soluble ones which give the earth mass a green or bluish green colour which is known as gleying process (Vysockij, 1905; Afanasiev, 1930).

Divalent iron compounds, being easily soluble in water, may be displaced in various directions according to whether the ground water is stagnant or running.

In the case of waters due to seepage or suffusion, the trend of migration of the iron compounds is determined by the direction of water movement. A totally different situation is that created by stagnant water for instance in swampy sites where reduced percolation does not favour the washing away of iron into underlying layers. In stagnant water, divalent iron compounds may spontaneously displace themselves into zones with a higher oxidation-reduction potential (higher degree of oxidation). Accordingly, the movement of iron is here commonly ascendant, rarely lateral. This upward movement of iron is not so much an effect of suffusion and evaporation of water as a result of oxidation owing to which the dissolved divalent iron compounds are converted to insoluble and coloured ferric hydroxides. The upward movement of divalent iron in swampy grounds is easily accounted for by the action of physico-chemical agents. It is effected as a result of the ground solution tending to compensate concentrations. The upward movement is continuous because in each case of differential oxidation-reduction potentiality and but a slightly acid reaction of the environment, the ground solution is inapt to attain an equal concentration of divalent iron salt. This regularity occurs as well in grounds that are completely soaked as in such which are thoroughly water-saturated.

In highly saturated grounds with varying grain-size gradation (e.g. sands and loesses) the oxidation zone, in enlarging the reach of its action, proceeds slowly, retaining at the same time its clearly marked outlines. The impossibility to compensate the concentration of divalent iron compounds in a ground solution with a differentiated oxidation-reduction potential is due to the fact that at the very peripheries of the oxidation zone, these compounds are already transformed into an insoluble residue. The margin of the oxidation zone which constitutes a boundary between two antagonistic systems may be compared to an electrode on the surface of which accumulates the residue produced by the flow and the annihilation of the electrolite. If there is an essential difference between the oxidation-reduction potentials and if the separating boundary does not change its position too rapidly, the increasing streak of iron precipitates is strongly impregnated and shows a well-defined outline.

Such a gradual development of the streak of rusty iron precipitates entails a considerable loss of iron in the reduction zone, particularly in those of its parts that border directly on the oxidation zone. Hence, for instance, water-suffused sandy or silty formations often show gley-eluvial microeluvia, directly underlying the oxidation zone. The phenomenon can be also reproduced in the laboratory as shown in photo 1.

The thickness and the degree of bleaching of the gley-eluvial zone were established by the present writes (Siuta & Motowicka-Terelak, 1965) owing to the following factors: (a) intensity of reduction processes, (b) grain-size gradation, (c) rate of enlargement of the oxidation zone at the expense of the reductive one.

This is true not only of areas subjected to ground water action but also of local reduction of the ground environment generally as a result of the decay of larger centers of organic matter such as dead logs, plant roots, etc. This question will be more amply discussed in connection with that of the corresponding forms of ferruginous precipitates.

One of the most controversial problems (in the literature) is that of the interpretation of the origin of a variety of bands and streaks formed by ferruginous precipitates in sand and loess formations. The majority of experts are inclined to see a direct genetic relationship between system and dynamics of hydrologic conditions on the one hand, and occurrence and character of the ferruginous precipitates on the other. The existence of such a relationship has been advocated by: Sukachev (1903), Glinka (1903), Aarnio (1915), Bystrov (1936), Strakhov (1947), Fersman (1955), Terlikowski (1958), Dietrich (1958), Gayel & Trushkovskij (1962).

Many workers — foremost experts in soil genetics and soil--systematics — hold that the horizontal streaks of ferruginous precipitates, occurring in sandy formations arose as a result of the podzolisation.

Such precipitates are of the nature of illuvial horizons formed as an effect of a strongly bleaching wood-mantle, especially if composed of coniferous trees. This view although more often set forth in personal communications than in scientific treatises, was however been also expressed in several publications, even in text-books (Sukachev, 1939; Żółciński, Haupt, Musierowicz, 1931; Mieczyński, 1939; Prokoshev, 1952; Stefanovits, 1960).

For the sake of accuracy, it may be appropriate to add that Sukachev, in attributing the origin of the horizontal streaks of ferruginous precipitates to the forest-mantle, does not expressly stress the process of podzolisation. Sukachev who studied the phenomenon in question in the southern part of Russia (woodless area) assumes that the presence of ferruginous precipitates, which are found only in depressions proves that ground water appeared here once within the soil profile thereby promoting the development of forest vegetation in steppe areas. Sukachev's argument is basically correct; this does not mean, however, that it should lead to the conclusion that the area investigated was wood-covered in the past. The presence of forests is by no means a prerequisite condition for the formation of that type of ferruginous precipitates. As a matter of fact the presence of woods provides conditions that are less suitable for the formation of horizontal streaks than those created by grass-vegetation. In contrast to the deep-reaching tree-roots, the shallow root-system of grass-plants does neither inhibit the formation of horizontal streaks nor interfere with their actually developed elements. This remark applies as well to the conclusions reached by Stefanovits (1960) who following the main trend of Sukachev's reasoning interpreted the history of the vegetal cover and the origin of certain sandy soils in Hungary.

While reviewing the literature of the subject it might be interesting to recall the valuable paper by Gayel and Trushkovskij (1962) who, in connection with dry steppe regions have set forth a highly original interpretation of horizontal streaks of ferruginous precipitates as indicators of the evolutional history of the relief pattern and of hydrologic and climatic conditions dating many thousands years back. For, the investigations of these workers have shown that the arrangement of the streaks in question is parallel to the surface of the ancient relief pattern which is entirely preserved in those places where it became overlain by dune sands. Furthermore, these writers see a close relationship between the origin of ferruginous precipitates and the system of hydrologic conditions in the past. Besides, their conclusions have been corroborated in a number of paleoclimatical and paleobotanical publications.

A wholly different conception of the origin of bands and streaks of ferruginous precipitates has been set forth by Krivan (1958). According to this writer, the origin of ferruginous precipitates is a direct result of the up-freezing of the ground. His hypothesis rests on the assumption that during the up-freezing of the earthy mass, the gradual crystalization of the water increases the condensation of the ground solution. This reasoning may be based on an analogy with the well-known phenomenon of crystallization of water in colloidal systems, like for instance during the up-freezing of a living cell, either vegetal or animal. Krivan's idea might be regarded as a near approach to truth if it did concern colloid hydroxides instead of real solutions. For the former are practically insoluble in water, while divalent iron is soluble since it does not undergo oxidation in either low temperatures or as a result of increasing concentration of the solution. The degree of solubility of divalent iron is besides an exceptionally high one that can by no means be paralleled with e.g. that of $CaCO_3$.

The influence of ground up-freezing upon the upward movement of iron compounds and a certain accumulation of this component on surficial soil layers, is a problem that aroused interest already long ago. Evidence of that interest is found foremost in the works by Yarkov (+ in 1956). Yarkov has established that the process of up-freezing of the ground does not reduce its divalent iron content; it however considerably reduces the soluble aluminium contained in the soil, a fact that is quite natural from the view point of physico-chemistry.

Rudniev (1960) mentions likewise the possibility of an upward movement of iron in the soil profile.

The present writers are also informed through personal communications of the investigations conducted by Nogina (Moscow). Her results, however, do not seem to indicate that up-freezing of the ground is likely to contribute to the formation of well-marked streaks of ferruginous percipitates.

Up-freezing of the ground surface causes the soil solution i.e.

also its mineral components to move upward, provided the earth mass is not to highly saturated. Up-freezing of the ground surface creates a sort of dryness that favours the upward movement of water which usually contains various mineral components including a certain quantity of iron. It should however be remembered that ground with a moderate degree of moisture, contains but an insignificant amount of water-dissolved iron which is therefore inapt to form any rusty brownish streaks, the more so as the zone of up-freezing continually changes its position.

Krivan's (1958) interpretation of the origin of ferruginous precipitates must have appeared convincing since it gained acceptance by such experts as A. Cailleux (1965, 1966) and Bertouille (in a joint study with Cailleux, 1966). Cailleux holds that Krivan's hypothesis seems plausible since it logically accounts for the various intricacies in the arrangement of bands and streaks of ferruginous precipitates. And, in fact, no other reasonable and experimentally documented explanation of the origin and mode of formation of that intricate pattern has been set forth until quite recently.

A first attempt towards a more detailed interpretation of the phenomenon in question on the basis of laboratory experiments was made by Siuta (published 1960). In particular two photographs showing the intricate pattern of bands and streaks of ferruginous precipitates, obtained experimentally in the laboratory, are amply discussed in this work. Further publications relating to this problem appeared in the following years: Siuta & Gawęda (1961) and Siuta & Motowicka (1963, 1965). The most recent work was devoted to the origin of horizontal streaks of ferruginous precipitates in sandy formations (Siuta & Motowicka, 1965). Most of the doubts formulated by Krivan, Cailleux, Bertouille, and many other geomorphologists, especially by experts on periglacial phenomena, were discussed in this paper.

A tentative explanation of the parallel and even combined occurrence of widely varying forms of ferruginous precipitates and lithologic deformations was set forth by Siuta (1962) who stresses the role of gases (as agents of deformation of the natural textural pattern) derived from the anaerobic fermentation of the organic matter contained in the silts and fossil humus horizons, so abundantly described by periglaciologists. Decomposition of organic matter under conditions of excessive ground moisture leads to a deformation of the texture and at the same time mobilises notable quantities of divalent iron. Such phenomena even though most conspicuous under periglacial conditions, are by no means absent from temperate and hot e.g. tropical climatic regions.

In summarizing the present state of these problems as outlined above, it might be worth adding that the origin of the various forms of ferruginous precipitates is not directly due to any either permanent or periodical presence in the ground environment of notable quantites of divalent iron compounds which being in a state of ground solution easily penetrate into zones and segments with a positive oxygen balance. In those places oxidation $Fe^{\cdot\cdot} \rightarrow Fe^{\cdot\cdot\cdot}$ takes place together with precipitation of rusty brownish iron hydroxides. The shapes of these rusty brownish ferruginous precipitates are usually identical or aproximate copies of the routes (fissures, channels, bubbles, etc.) or of the conductive zones of oxygen into the reduced ground environment (Pl. 2). Therefore, only the air-water conditions of the ground environment can be deduced from the shape and location of ferruginuos precipitates; these however afford no tangible evidence concerning the time period in which the phenomenon arose. The presence of horizontal streaks of ferruginous precipitates in sandy deposits may, therefore, be used to determine the sequence of environmental modifications provided that such a determination be based on a sound geomorphologic analysis with a particular consideration of the hydrological and paleobotanical interrelations.

In order to emphasize the importance of the above conclusions particular attention should be given to the significant dynamics of oxidation-reduction processes which are apt to form streaks of ferruginous impregnation within a short time. These streaks may also rapidly undergo further reduction and annihilation, if the ground environment provides suitable conditions (Pl. 3).

## PRINCIPLES OF DIVISION OF FERRUGINOUS PRECIPITATES

Ferruginous precipitates fall into two categories: cencretional and non-concretional (Fig. 1). The difference between concretional and non-concretional forms depends on their degree of cementation. Concretional forms being strongly cemented can be separated from the ground environment while the non-concretional ones retain their morphologic appearance solely on the background

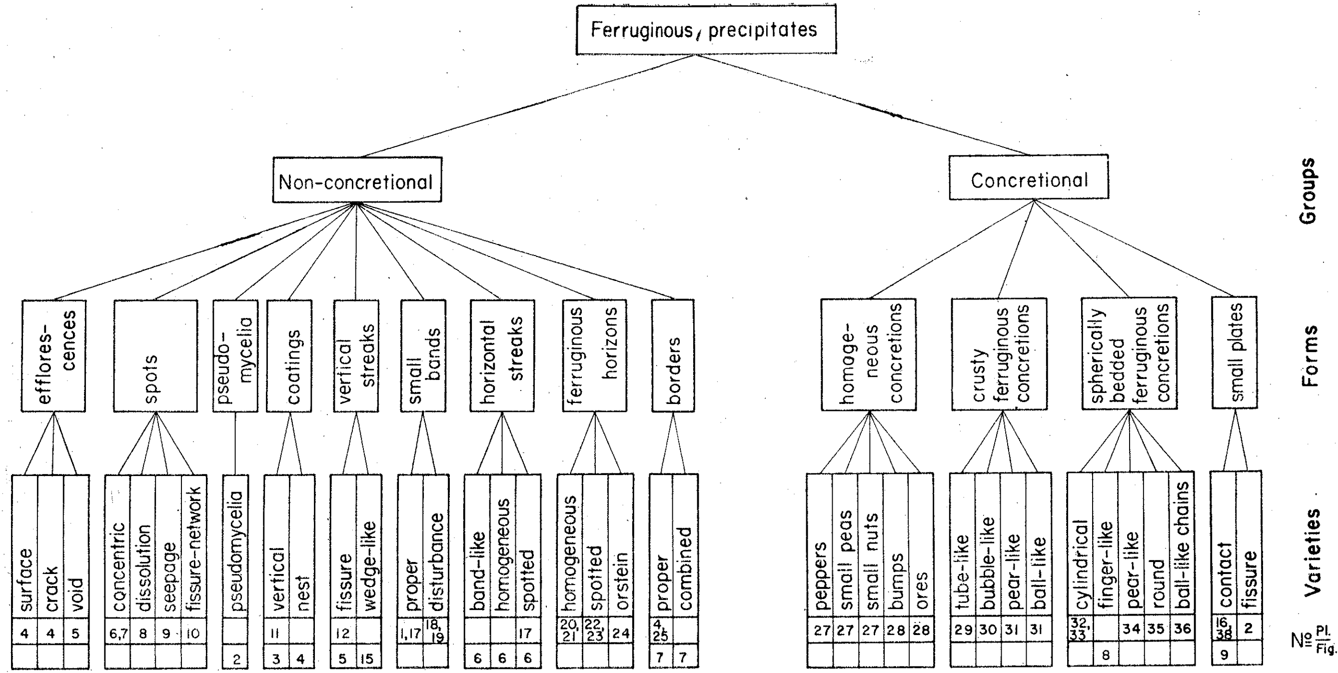
Ferruginous, precipitates
Non-concretional
Concretional
efflores-cences
spots
pseudo-mycelia
coatings
vertical streaks
small bands
horizontal streaks
ferruginous horizons
borders
homoge-neous concretions
crusty ferruginous concretions
spherically bedded ferruginous concretions
small plates
surface 4
crack 4
void 5
concentric 6,7
dissolution 8
seepage 9
fissure-network 10
pseudomycelia 2
vertical 11 3
nest 4
fissure 12 5
wedge-like 15
proper 1,17
disturbance 18, 19
band-like 6
homogeneous 6
spotted 17 6
homogeneous 20, 21
spotted 22, 23
orstein 24
proper 4, 25 7
combined 7
peppers 27
small peas 27
small nuts 27
bumps 28
ores 28
tube-like 29
bubble-like 30
pear-like 31
ball-like 31
cylindrical 32, 33
finger-like 8
pear-like 34
round 35
ball-like chains 36
contact 16, 38 9
fissure 2
Groups
Forms
Varieties
No Pl. / Fig.

Fig. 1.

of the structure within which they were formed. The basic unit of division is a given form which includes a number of varieties. The adoption of „form" as a basic divisional unit may arouse suspicion as to whether such a division is of the nature of a genetic systematization. It must be, therefore, very clearly understood that in the case under discussion a „form" constitutes the most reliable record of the environmental conditions under which it was modelled.

The varieties belonging to one and the same form of ferruginous precipitates, convey more detailed information concerning the physico-chemical properties and the dynamics of the biochemical processes within the ground environment. The forms and varieties of ferruginous precipitates as well as their location in the profile (of varying grain-size gradation) are presented in table I. This table is supplemented by several illustrations in the text.

The distribution of the individual forms of ferruginous precipitates presented in table I is of a general schematic character. It fails to show the variations of air-water conditions commonly occurring in soils belonging to each of the particular grain-size groups. Such a schematic presentation of the problem is inavoidable since ferruginous precipitates (such, for instance, as are characteristic of periodically water-saturated or even boggy sites) occur for the main part in soils whose air-water conditions have been regulated long since. Thus, table I shows the possibility of occurrence of the particular forms and varieties of ferruginous precipitates, dependantly on the grain-size gradation and the depth of a given soil profile. It does not mean, however, that the ferruginous precipitates shown in table I do actually occur in every soil profile. Certain soil types such as e.g. chernozems and brown forest soils do practically never exhibit any concretional ferruginous precipitates (especially no homogeneous concretions) while in similar podzols and pseudopodzols, concretions are very common. An accurate description of each of the particular forms of ferruginous precipitates requires a clear presentation of the specific environmental conditions within the ground under which they were formed. In other words, the totality of the surficial deposits should — irrespective of their grain-size gradation — be devided into groups according to their system of air-water conditions. These groups will be defined as *hydrologic types of ground environment*. Such a designation was adopted because of the necessity to find a comprehensive term that might be apt to include the totality of ground formations from dry soils to boggy grounds.

The following hydrologic types of ground environment were distinguished:

A — dry grounds
B — grounds with optimal water conditions
C — periodically over-moist grounds
D — periodically soaked grounds
E — permanently soaked grounds
F — periodically marshy grounds
G — boggy grounds
H — submerged grounds (slimes)

Most of these hydrologic types does not seem to require any further explanations. Some doubts may only arise as to the necessity of a distinction between two groups of grounds containing a periodical excess of water such as periodically over-moist and soaked grounds. Both these definitions are seemingly similar as both hydrologie types may be taken to belong to one and the same type. In fact, however, they actually do represent two different hydrologic states. Periodically soaked grounds are characterized by a shallow ground-water table which appears periodically in the central, sometimes even in the upper part of the soil profile. Periodically over-moist grounds fail to show any shallow ground-water table. What is called ground-water table may even be entirely absent. Such is for instance the case in loess deposits underlain by vigorously draining sediments (sands, gravels, limestones). Periodical excess of water in that type of ground is due to the presence (in either the upward or the central part of the profile) of less pervious layers and soil horizons. Periodical excess of water occurs, therefore, in the up- instead of the downward part of the profile which induces a periodical development of gleying from above. A clear distinction between periodically over-moist and periodically soaked grounds is a very essential one for the study of natural phenomena.

The introduction and a correct interpretation of the term *hydrologic types of ground environment* fails, however, to provide a basis that might permit to account in detail for the origin of the perticular forms of ferruginous precipitates. The difficulty comes from the fact that one and the same soil or soil group belonging to one and the same hydrologic type show a considerable amplitude of air-water conditions. In other words, a hydrologic type may at times be found in such a state of air-water conditions as is characteristic of other types. The range of fluctuations of air-water conditions and the time length of certain states are reflected in either the development or the disappearance of gleying.

A detailed description of the possible combinations of air-water conditions within each of the particular types of hydrologic ground environment would require too much space and time. It will therefore be presented (in table II) with the help of another new term namely that of *form of gleying.*

This term has been introduced in the instructions concerning all the Polish small-scale cartographic soil surveys (1965). The particular forms of gleying in the ground environment are more amply discussed in a separate publication (S i u t a, 1967). The following forms of gleying will be referred to below (state and degree of reduction): (a) spotted, (b) marbled, (c) zonal, (d) complete, (e) dispersed (local), (f) produced by seepage.

Various forms of gleying (symbols: a, b, c, d, e, f) with reference to grain-size gradation, depth of the deposit (I a, b, c; V a, b, c) and hydrologic type of the ground environment (A, B, C, D, E, F, G, H) and their — even sporadic — occurrence are presented in tab. II. Each of the forms of gleying may occur either sporadically, periodically or be of a permanent nature. The following signs have been employed to mark the frequency and duration of each of the peculiar forms distinguished:

$a^{+}$, $b^{+}$, $c^{+}$, $d^{+}$, $e^{+}$, $f^{+}$ — phenomena occurring sporadically,

$a^{++}$, $b^{++}$, $c^{++}$, $d^{++}$, $e^{++}$, $f^{++}$ — phenomena occurring periodically, generally in connection with seasonal changes,

$a^{+++}$, $b^{+++}$, $c^{+++}$, $d^{+++}$, $e^{+++}$, $f^{+++}$ — permanent phenomena.

## DESCRIPTION OF THE FORMS AND VARIETIES OF FERRUGINOUS PRECIPITATES

### EFFLORESCENCES

Efflorescences are divided into such as appear (1) at the surface, (2) in cracks, (3) in voids. Most common and easily discernible are those appearing on the surface. The formation of efflorescences is directly due to the presence in the ground environment of readily soluble divalent iron compounds which, either carried by water or owing to compensation of concentrations, are brought on to the ground surface and into oxidized (having a contact with the atmosphere) cracks and voids. There, the soluble divalent iron compounds undergo oxidation and are converted to hardly soluble, rusty-brownish ferric hydroxides.

The presence of surfical efflorescences being most conspicuous in compact formations such as lumps and knots proves that the soil was subjected to an intensive, either periodical or permanent process of gleying. Surficial efflorescences are common in periodically soaked soils and, thereby, facilitate a recognition of this type of air-water conditions, especially so if field work is conducted during a dry summer season when the soil clearly shows a lack of moisture. Such instances are often encountered in sands which even though belonging to the category of periodically soaked soils are at the same time susceptible of periodical aridity.

The efflorescences occurring in cracks and hollows are formed in cohesive formations alone, whose grain-size gradation promotes the formation and preservation of cracks and voids within the earth mass. Crack-efflorescences are generally characteristic of:

(a) clays and tills (sometimes also clayey silts) with periodically excess of moisture (accompanied by progressive gleying) and upheaving alternating with seasonal drying up and shrinking (cracking) of the ground;

(b) clays, tills, pulverulent deposits and more compact sands (resulting from compression) which are often found near (in) brickkilns if heavy machines were used to work the earth (Pl. 3);

(c) lithologic-gleyey, fine-grained water-laid sediments (slimes in water resorvoirs) subjected to periodical desiccation during which many fissures are formed which come into direct contact with oxygen, either atmospheric or dissolved in water.

## SPOTS

Spots constitute the most common shape of dispersal concentration of ferruginous precipitates. The presence of black spots indicates that the oxidation-reduction system of the ground environment underwent remarkable fluctuations. Like all precipitates, spots are formed in soils having either a periodical or a permanent content of water dissolved divalent iron compounds which become oxidized within variously shaped channels, voids and earth cracks. The shape, the contents and the time of duration of the precipitates defined as ferruginous spots depend on the form of the empty spaces within the soil, on the quantity of the iron deposited, and on the degree of cementation. Hence, the term *spots* includes the totality of feebly cemented ferruginous precipitates that fail to show any well-defined and long-lived forms. This category comprises all the non-concretional elements of ferruginous precipitates which cannot be ascribed, on the basis of their morphologic features, to any of the other divisional groups. Spots may, therefore, also include some underdeveloped or partly destroyed elements of the other forms of ferruginous precipitates.

Generally, though not as a rule, ferruginous spots have a rusty-brownish colour. Dark gray or even quite black spots are often encountered (Voronova, 1960). Such colours are due to a secondary but only partial reduction of the previous rusty spots (viz. quotation from Książkiewicz, 1959).

Black spots which are sometimes erroneously interpreted as humus agglomerations, provide evidence of widely varying oxidation-reduction conditions within the ground environment which shows that the oxidized segments underwent further reduction. The phenomenon in question was tested experimentally in the laboratory (Siuta & Gawęda, 1961).

Spots fall into four varieties: (1) concentric spots, (2) dissolution spots, (3) seepage spots, (4) fissure-network spots.

Concentric spots are clearly outlined (on the background of a cut or a break in the earth mass) in the form of points, either isolated or grouped, of concentrated iron compounds, usually of a rusty-brownish, rarely of a plainly black colour. Concentric spots predominate in the upward part of the soil profile where biogenic gases, generally concentrated in the form of bubbles, create within the earth mass (in the period of over-saturation) a whole number of channels and voids. While the excess water recedes, atmospheric oxygen enters the formerly gas-filled channels and voids thus oxidizing the previously reduced soil substance. As a result a rusty residue of trivalent iron compounds is precipitated on the wall surfaces of various void spaces. Such accumulations of iron may be relatively large because dissolved divalent iron compounds flow (for a certain time) from the surrounding soil into the oxidized places. If the residue accumulates on the walls of a small void (preformed by a gas bubble) its initial appearance is that of an efflorescence, which subsequently changes into a thin shell (of a hydroxide bubble) until it finally becomes a tiny homogeneous ball.

A cross cut or a break through each of the forms mentioned above discloses a pattern of concentric spots. If the process of hydroxide concentration continues for a relatively long time (a fact usually connected with a definite rhythm of air-water conditions) the residue becomes strongly cemented and may therefore be easily extracted from its surroundings. This means that with the accumulation and the progress of cementation of the iron hydroxide, the concentric spots are transformed into homogenous concretions.

Dissolution spots — as may be inferred from their name — fail to show any clearly marked morphologic character (Pl. 8). They are formed in places where the dynamics of air-water conditions is sufficiently potent to inhibit the development of the other better-defined forms of ferruginous precipitates. Dissolution spots occur usually in periodically soaked sandy grounds. Such spots are also found in ground which, although dry to-day, were water-covered in the past. A perfect example of that kind of black spots is shown in photo 24, in Krzemiński's work (1965).

Seepage spots are, in principle, of the same origin as a certain kind of crack efflorescences. The difference between them consists in the fact that in a description of a natural lithologic-soil section or in a view of the surface of various structural elements (crumbs, lumps, pillars, etc.) of the ground formation they appear as crack efflorescences. A mechanically obtained lithologic section shows, however, a different picture in which the vertical crack efflorescences assume the character of seepage spots (Pl. 9).

Fissure-network spots occur within formations which being more compact and less pervious are likely to crack during desiccation along both vertical and horizontal lines. In these fissures, rusty iron hydroxides accumulate thus forming an intricate network pattern on the background of a vertical cut through the soil (Pl. 10). Similar networks of ferruginous precipitates are also found in formations undergoing a stage of gradual disappearance (oxidation) of gleying.

## PSEUDOMYCELLIA

Pseudomycellia[1] are spread on the walls of the tiny channels formed within the soil by plant roots and during the phase of

[1] The term *pseudomycellia* applies also to analogous forms of $CaCO_3$ precipitates commonly found in loessy formations.

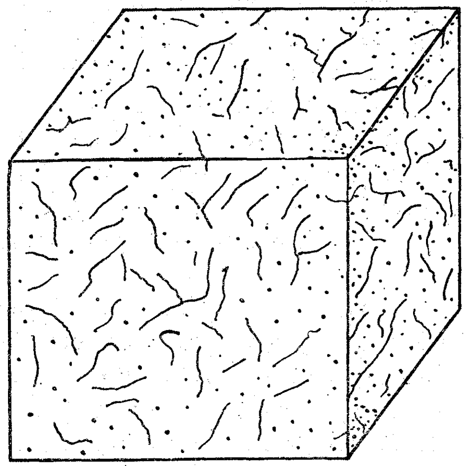

Fig. 2. Ferruginous precipitates — so-called pseudomycellia

gas circulation. Pseudomycellia occur generally in the humus horizon of soils that are periodically suffused with water. They are found also in the eluvial horizons of podzolic or pseudopodzolic soils. Exceptionally only in certain mades, either light or medium, do pseudomycellia occur in the central part of the soil profile.

The origin of pseudomycellia is, like that of concentric spots, a direct result of a periodically intensive though short phase of gleying of the ground environment within which soluble divalent iron compounds are formed. On the recession of excess water, atmospheric air penetrates the reduced soil thus inducing oxidation of the iron compounds and precipitation of the residue on the walls of channels and other voids within the soil.

## COATINGS

Coatings are streaks of rusty brownish ferruginous precipitates running along the border line between post-gley bleachings and the unaltered (in colour) ground environment. Bleaching of that type (gley-eluvial) are produced as a result of the decay of local accumulations of organic matter which while subjected to gleying, cause divalent iron to migrate beyond the limits of the reduced zone where the iron becomes oxidized and converted to its insoluble forms.

The majority of ferruginous coatings are a result of the decomposition of dead trunk roots. Hence the multiform shapes of the post-gley bleachings which they border (coat); in the cross--cut, these shapes are generally circular or ellipsoidal (Pl. 11). The occurrence of ferruginous coatings indicates that the soil, though not actually suffering from any oxygen defficiency, is — owing either to the presence of a larger content of organic matter or to increased compression — likely to become rapidly under--oxidized. Ferruginous coatings do not, therefore, provide any evidence of abnormal water conditions within the soil. They only reveal its tendency to defficiencies induced by inappropriate agrotechnical methods or by an exceptionally high rate of precipitation.

Coatings fall into two categories: (1) vertical, and (2) nest coatings.

Vertical coatings arise on the margins of zones that are reduced (gleyed) by organic matter derived from the decomposition of trunk roots which often reach to considerable depths of the soil profiles. In the vertical cut through a post-gley bleaching with its coating, it usually has the appearance of a tapering wedge which visibly contrasts with the surrounding parent formation (Fig. 3, Pl. 11).

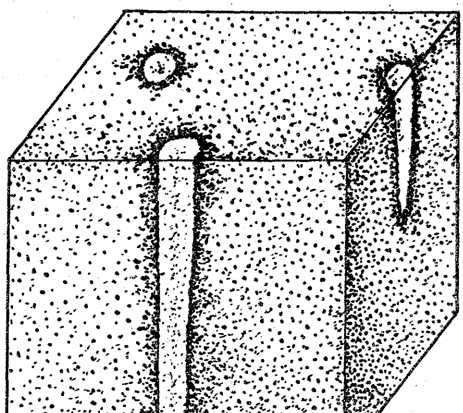

Fig. 3. Vertical and cross-section through the vertical coatings

Nest coatings, on the contrary, fail to show any well--defined shapes. They form around larger agglomerations of organic matter which are generally situated in the upward, rarely in the central part of the soil profile. The nests of organic matter that induce local gleying may be derived from manure, green fertilizers, post-harvest remnants and the dead roots of either trees or shrubs.

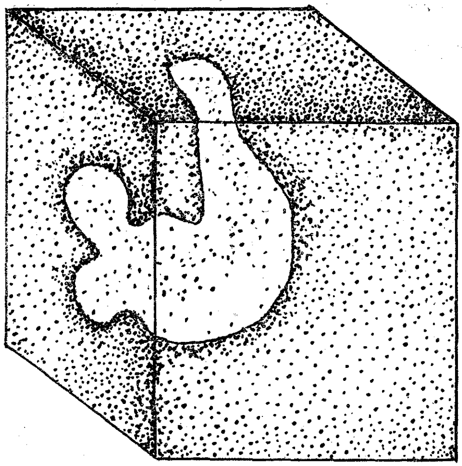

Fig. 4. Nest coatings surrounding the gley-eluvial zones formed by the decomposition of cow manure, green manure or harvest remains

A common feature of all ferruginous nests is that each of them borders (encircles) a definite (gley-alluvial) ground fragment that once underwent intensive gleying. A peculiar characteristic of ferruginous coatings is that their centerward (towards the center of reduction which is now a gley-eluvial element) is well-marked, while the outward side has the appearance of a dissolution streak whose extension is not easy to define (Fig. 4).

VERTICAL STREAKS

Vertical streaks are subdivided into (1) fissure-like and (2) wedge-like.

In the soil profile, v e r t i c a l f i s s u r e - l i k e streaks bear a striking resemblance to the ferruginous coatings described above. The only difference consists in the fact that instead of forming around dispersed gleyed fragments, they arise in the vicinity of soil cracks into which excess water percolates easily, carrying a certain amount of dissolved organic components. Hence, vertical fissures which, as long as they are dry may contain an abundance of air, undergo periodical reduction which, though short-lived is nonetheless vigorous. The reduced iron compounds — being water soluble — migrate vertically to the adjoining zones where they are oxidized and precipitated in the form of a rusty brownish streak. Such streaks appear on both sides of the fissure; a vertical cut shows therefore a pattern similar to that of a cut through a vertical coating. In the horizontal cut, however, vertical streaks visibly differ from coatings, for instead of forming a circle they show two, rather parallel streaks, with contours which — like in the coatings — are well-marked at the inner, gley-eluvial side (Fig. 5, Pl. 12 B). It is correct to regard vertical fissure streaks

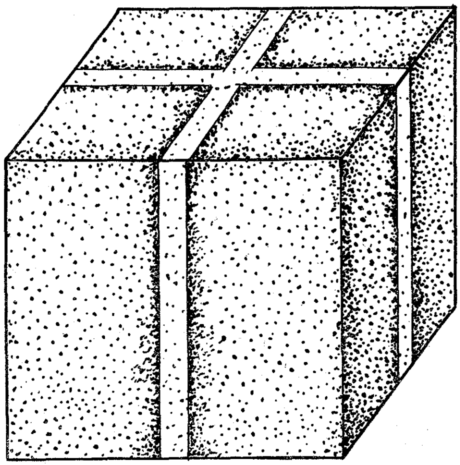

Fig. 5. Vertical view and cross section through vertical fissure streaks

as a separate unit because streaks provide evidence of a natural and continuously renewed defficiency of the soil, whereas coatings only disclose a tendency of the soil to local manifestations of defficiency.

Vertical fissure streaks occur invariably in formations consisting of equal and fine grained components which are likely to modify their volume according to either moisture or desiccation of the ground. An excess of colloidal silts inhibits, however, the formation of such streaks, for too compact a formation fails to provide suitable conditions for a rapid oxidation of the divalent iron contained within the fissures.

Best-developed are the vertical fissure streaks occurring in loess soils with clayeyfied horizons that render percolation difficult and thereby lead to periodical excess of moisture in the uppermost ground layers — a phenomenon that is commonly encountered in submontane regions, with abundant precipitation. The illuvial horizon of such soils is intersected by vertical light-grey, gleyey-eluvial streaks which form a kind of dendritic podzolic horizon (Pl. 14). Mihailescu (1964) cited a similar soil as an example of frost-action in Dobrudja. But his assumption seems rather unlikely.

Wedge-like vertical streaks (Pl. 15) occur commonly in sands and gravels of glacial accumulation where they border the outward sides of wedges and other similar ground forms which differ from their surroundings by a more compact grain-size composition. These streaks accentuate the boundary between the fine grained (weathered) wedge mass and the rest of the sand- or gravel bed. Wedge streaks are formed with the assistance of gleying that occurs seasonally within wedges that are — owing to a more compact grain-size gradation — apt to retain excess water during periods of increased precipitation. An analogous process of gleying and migration of iron took also place in the subsurficial zone which developed the eluvial horizon whose continuations are the wedges in question. The uniformity (continuity) of the formation of the eluvial horizon and bleachings within the wedges may be easily traced in the illuvial horizon which, here and there, passes into vertical wedge-like streaks (Pl. 15). The intensity and the fluctuations of reduction processes in various parts of the profile can be inferred from the degree of development and the conspicuous appearance of the streaks of ferruginous precipitates. It is clearly visible in Pl. 15 where the centerward (reductionward) edges of the ferruginous streak appearing at wedge level is very well-marked, while in the upper part it has a diffused appearance. Moreover, wedge streaks in contrast with fissure streaks, are no present-day phenomena but relics of Pleistocene periglacial times and represent, therefore, an object of theoretical, scientific rather than practical interest. Vertical wedge streaks have already been described by many investigators (Dylik, 1956, 1966; Dylikowa, 1956; Maruszczak, 1960; and Czerwiński, 1964).

## SMALL BANDS

Bands are known in the literature as pseudo-fibres (Żółciński, Haupt, Musierowicz, 1931; Mieczyński, 1939). The variety includes ferruginous precipitates which are so well--marked in the soil-profile as to give the impression of alien intrusions. Owing to their considerable cementation and to their well-defined outline, such bands may be easily extracted from the parent material, especially if this consists of such dry fine-grained material as loose or feebly clayey sands (Pl. 19) or silts with a small content of colloidal clays.

Ferruginous bands owe their origin to a specific system of air--water conditions either past or recent. Bands of that type can be formed in those cases alone when fluctuations of the ground-water table are insignificant and occur slowly over long periods.

This assertion is supported by many works in which the geomorphic situation and the conditions of occurrence of ferruginous bands and streaks have been described and illustrated. These works clearly show that a large majority of such precipitates are found in formations bordering directly on river valleys, lakes and bogs. An attentive study of the works by Klatkowa (1965) and Krzemiński (1965) reveals a close relationship between the origin of formations and elements of the relief pattern on the one hand and the occurrence and character of ferruginous precipitates on the other. Easily discernible is also the fact that a genetically homogenoeus complex of sandy deposits (especially outwash-plain sands) may widely differ in occurrence, number and degree of development of the ferruginous precipitates.

The majority of the ferruginous bands encountered to-day fail to reflect the actual system and the dynamics of water conditions within the soil. Although they are relics of the past, their importance is not only that of a historic indicator, for the very presence of such elements in the profile tends to reduce excessive percolation of rain water and thereby largely influences the system of hydrologic conditions in present-day sandy soils.

The divergent views found in the literature concerning the origin of that type of ferruginous precipitates have been already discussed above. Some additional details might however be worth quoting. Sukachev (1903) for instance, cites an example of horizontal streaks of ferruginous precipitates running across mole--hills, subsequently filled with alien material. A similar phenomenon, though on a much larger scale, was observed by J. Kowalczyk in the course of archeologic research-work in Klementowice (personal communication) where a re-filled „earth-hole" within the loess was intersected by streaks of ferruginous precipitates, extending into the depth of the underlying loess. Such examples prove that the ferruginous precipitates in question, were developed relatively late since they appear in the infillings of hollows produced by the activity of man (Neolith) and of soil fauna (Sukachev, 1903).

Bands are subdivided into (1) bands proper, and (2) disturbance bands.

The bands proper (Pls. 16, 17) show a more or less parallel arrangement of horizons in the soil profile. Their presence indicates that the boundary between two opposed oxidation-reduction systems was modified at intervals (in leaps) though it dit not provoke any serious local disturbances.

Disturbance bands (Pls. 18, 19) though having in fact the same origin as the bands proper, show however an intricate pattern of the boundary (separating two opposed oxidation-reduction systems) which is the site of accumulation of iron hydroxides. These intricacies are chiefly due to: (a) locally increased passage of oxygen, (b) a larger quantity (than in the surrounding soil) of organic matter (e.g. derived from decomposed tree roots), (c) multiplied pulsations of the three-phase system compounds (ground, water, gas) especially in desiccated places and other textural deformations.

### HORIZONTAL STREAKS

Horizontal streaks fall into three varieties: (1) band-like, (2) homogeneous, (3) spotted. A common feature of these three varieties is the horizontal extension of the ferruginous precipitates appearing in the soil profile in the form of various streaks. Horizontal streaks constitute a connecting link between bands and horizons.

Band-like horizontal streaks despite their resemblance to bands differ from them in that they are thicker and their outlines are less defined. Horizontal streaks are often an effect of merging into one another of several parallel bands, as a result of short but recurrent periods of opposed oxidation-reduction systems which are closely associated with the rhythm of the hydrologic factor.

The distinction made between bands and band-like streaks is well-founded in so far as the former (if well-developed) mark a single-time limit (between two opposed oxidation-reduction systems) which owing to a gradual lowering of the ground-water table shifts usually abruptly farther down the soil profile. Hence a horizontal streak composed of a number of tiny ferruginous bands

Table I

Forms and varieties of ferruginous precipitates in various soils of Poland

| Form | Variety | No. of Variety | No. of Pl. | No. of Fig. | Textural groups, depth in cm: Loose-sandy soils and coarse-sandy soil 0—40 (50) | 40 (50) —80 | 80 | Medium-grained sand 0—40 (50) | 20 (50) —80 | 80 | Sandy loams and medium heavy loams 0—40 (50) | 40 (50) —80 | 80 | Clayey loams and clays 0—40 (50) | 40 (50) —80 | 80 | Silty loam 0—40 (50) | 40 (50) —80 | 80 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Non-concretional forms of ferruginous precipitates | | | | | | | | | | | | | | | | | | | |
| Efflorescences | surface | 1 | 4 | | + | | | + | | | + | | | + | | | + | | |
| | crack | 2 | 4 | | | | | | | | + | + | + | + | + | + | + | + | + |
| | void | 3 | 5 | | | | | | | | | | | | | | + | + | + |
| Spots | concentric | 4 | 6, 7 | | ++ | + | | ++ | + | | ++ | | | + | | | +++ | + | |
| | dissolution | 5 | 8 | | +++ | +++ | + | +++ | ++ | + | ++ | ++ | + | ++ | + | + | +++ | +++ | + |
| | seepage | 6 | 9 | | | | | | + | + | + | ++ | + | + | ++ | + | + | ++ | ++ |
| | fissure-network | 7 | 10 | | | | | | + | | ++ | +++ | + | ++ | ++ | + | ++ | +++ | + |
| Pseudomycellia | | 8 | | 2 | +++ | | | +++ | | | ++ | | | ++ | | | +++ | ++ | + |
| Coatings | vertical | 9 | 11 | 3 | | | | | + | + | | ++ | + | | + | | + | +++ | ++ |
| | nest | 10 | | 4 | | | | ++ | + | | ++ | + | | | | | +++ | + | |
| Vertical streaks | fissure | 11 | 12, 13, 14 | 5 | | | | | | | | + | + | | | | | +++ | ++ |
| | wedge-like | 12 | 15 | | | ++ | + | | ++ | + | | | | | | | | | |
| Small bands | proper | 13 | 1, 16, 17 | | + | ++ | +++ | | | | | | | | | | | + | ++ |
| | distrurbance | 14 | 13, 19 | | | + | + | | | | | | | | | | | + | + |
| Horizontal streaks | band-like | 15 | | 6 | ++ | ++ | +++ | + | + | + | | | | | | | | ++ | ++ |
| | spotted | 16 | | 6 | ++ | +++ | + | + | + | | | | | | | | + | + | + |
| | homogeneous | 17 | 17 | 6 | ++ | ++ | + | ++ | + | + | | | | | | | + | ++ | + |
| Horizons | homogeneous | 18 | 20, 21 | | +++ | ++ | + | +++ | ++ | + | ++ | + | | + | + | | ++ | ++ | + |
| | spotted | 19 | 14, 22, 23 | | +++ | ++ | + | ++ | + | | + | + | | | | | ++ | ++ | + |
| | orstein | 20 | 24 | | +++ | ++ | | ++ | + | | | | | | | | + | | |
| Borders | proper | 21 | 4, 25 | 7 | | + | + | | + | + | + | + | + | | | | + | + | + |
| | combined | 22 | | 7 | | | | | | | | + | + | | | | | + | + |
| Concretional forms of ferruginous precipitates | | | | | | | | | | | | | | | | | | | |
| Homogenous concretions | peppers | 23 | 27 | | | | | | | | +++ | + | | + | | | +++ | ++ | |
| | small peas | 24 | 27 | | | | | + | | | +++ | + | | + | | | +++ | ++ | |
| | small nuts | 25 | 27, 28 | | + | | | ++ | + | | ++ | + | | | | | +++ | + | |
| | bumps | 26 | 28 | | ++ | + | | ++ | + | | + | + | | | | | ++ | + | |
| | ores | 27 | 27, 23 | | +++ | ++ | | +++ | + | | | | | | | | + | | |
| Crusty ferruginous concretions | tube-like | 28 | 29 | | | | | | | | + | + | + | | | | +++ | +++ | + |
| | bubble-like | 29 | 30 | | | | | | | | + | + | | | | | ++ | ++ | + |
| | pear-like | 30 | 31 | | | | | | | | + | + | | + | + | + | + | ++ | ++ |
| | ball-like | 31 | 31 | | | | | | | | + | + | | + | + | + | ++ | +++ | ++ |
| Spherically-bedded ferruginous concretions | cylindrical | 32 | 32, 33 | | | | | | | | + | + | + | + | + | + | +++ | +++ | ++ |
| | finger-like | 33 | | 8 | | | | | | | + | + | | + | | | +++ | +++ | ++ |
| | pear-like | 34 | 34 | | | | | | | | + | + | | + | | | ++ | +++ | ++ |
| | round | 35 | 35 | | | | | | | | + | + | | + | | | +++ | +++ | ++ |
| | ball-like chains | 36 | 36, 37 | | | | | | | + | | + | | | + | + | ++ | +++ | + |
| Small plates | contact | 37 | 16, 38 | | | | | | | 9 | | | | | | | | | |
| | fissure | 38 | 2 | | | | | | | | | + | + | | + | + | | ++ | + |

Table II

Scheme of occurrence and increase of gley processes in various textural groups and hydrological environments

| Textural group | | Depth in cm | Type of the ground hydrological environment and the existant forms of gley in it | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | A | B | C | D | E | F | G | H |
| | | | Dry grounds | Grounds with optimal walter condition | Periodically over-moist grounds | Periodically soaked grounds | Permanently soaked grounds | Periodically marshy grounds | Boggy soils | Submerged grounds (slimes) |
| I Loose and slightly clayey sand | a | 0—40(50) | non-existant | $a^{+}$, $e^{+}$ | | $b^{++}$, $c^{+}$ | $c^{+++}$, $d^{+}$ | $d^{++}$ | $d^{+++}$ | $d^{+++}$ |
| | b | 40(50)—80 | non-existant | $a^{+}$, $b^{+}$, $c^{+}$, $e^{+}$ | | $c^{++}$, $d^{+}$ | $a^{++}$ | $d^{+++}$ | $d^{+++}$ | $d^{+++}$ |
| | c | 80—120 | $b^{+}$, $c^{+}$ | $b^{++}$, $c^{++}$ | | $a^{++}$ | $d^{+++}$ | $d^{+++}$ | $d^{+++}$ | $d^{+++}$ |
| II Clayey sand | a | 0—40(50) | non-existant | $a^{+}$, $e^{+}$ | | $b^{+++}$, $c^{+}$ | $c^{+++}$, $d^{+}$ | $d^{++}$ | $d^{+++}$ | $d^{+++}$ |
| | b | 40(50)—80 | non-existant | $e^{+}$ | | $c^{+++}$, $d^{+}$ | $d^{++}$ | $d^{+++}$ | $d^{+++}$ | $d^{+++}$ |
| | c | 80—120 | $a^{+}$ | $a^{+}$, $b^{+}$, $c^{+}$ | | $d^{++}$ | $a^{+++}$ | $d^{+++}$ | $d^{+++}$ | $d^{+++}$ |
| III Loam: sandy and medium heavy | a | 0—40(50) | non-existant | $a^{+}$, $be^{+}$, $f^{+}$ | $a^{+++}$, $b^{++}$, $c^{+}$, $e^{++}$ | $b^{+++}$, $c^{++}$ | $c^{+++}$, $d^{+}$ | $d^{++}$ | $d^{+++}$ | $d^{+++}$ |
| | b | 40(50)—80 | non-existant | $a^{+}$, $e^{+}$, $f^{+}$ | $a^{++}$, $c^{+}$, $e^{+}$, $f^{++}$ | $c^{+++}$, $d^{+}$ | $d^{++}$ | $d^{+++}$ | $d^{+++}$ | $d^{+++}$ |
| | c | 80—120 | non-existant | $b^{+}$, $f^{+}$ | $e^{+}$, $f^{+}$ | $d^{++}$ | $d^{+++}$ | $d^{+++}$ | $d^{+++}$ | $d^{+++}$ |
| IV Clayey loam | a | 0—40(50) | non-existant | $a^{++}$, $b^{+}$ | $b^{++}$, $c^{+}$, $e^{+}$ | $b^{+++}$, $c^{++}$, $d^{+}$ | $c^{+++}$, $d^{+}$ | $d^{++}$ | $d^{+++}$ | $d^{+++}$ |
| | b | 40(50)—80 | non-existant | $e^{+}$, $f^{++}$ | $c^{++}$, $f^{++}$ | $c^{+++}$, $d^{+}$ | $d^{++}$ | $d^{++}$ | $d^{+++}$ | $d^{+++}$ |
| | c | 80—120 | non-existant | $f^{++}$ | $f^{+}$ | $d^{++}$ | $d^{+++}$ | $d^{+++}$ | $d^{+++}$ | $d^{+++}$ |
| V Silty loam | a | 0—40(50) | non-existant | $a^{+}$, $e^{+}$ | $b^{++}$, $c^{+}$, $e^{+}$, $f^{+}$ | $b^{+++}$, $c^{++}$ | $c^{+++}$, $d^{++}$ | $d^{++}$ | $d^{+++}$ | $d^{+++}$ |
| | b | 40(50)—80 | non-existant | $a^{+}$, $e^{+}$ | $b^{++}$, $c^{+}$, $f^{++}$ | $c^{+++}$, $d^{+}$ | $d^{++}$ | $d^{+++}$ | $d^{+++}$ | $d^{+++}$ |
| | c | 80—120 | non-existant | $e^{+}$ | $f^{+++}$ | $d^{++}$ | $d^{+++}$ | $d^{+++}$ | $d^{+++}$ | $d^{+++}$ |

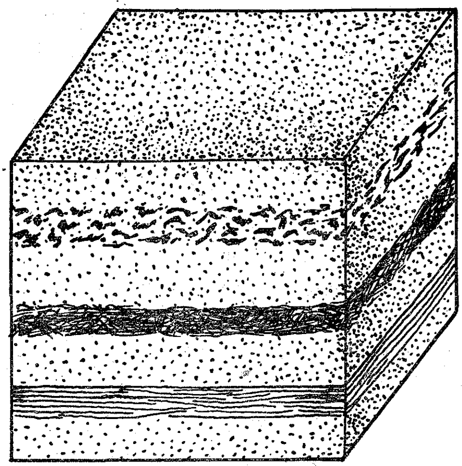


Fig. 6. Horizontal streaks: (a) band-like, (b) homogeneous, (c) spotted

provides evidence of recurrent fluctuations of the ground-water table and of very short-lived systems of opposed oxido-reductivity.

Furthermore, streaks (band-like ones in particular) occur commonly within the same soil profiles in the form of well-developed, single bands of ferruginous precipitates.

Homogeneous horizontal streaks are clearly discernible in the soil section though their external zones show a diffused appearance, merging into both the over- and the underlying ground mass.

Homogeneous horizontal streaks are, in fact, well-developed ferruginous microhorizons formed within the zone of slow fluctuations and mutual interaction of reduction and oxidation processes. Various present-day soils in Poland afford suitable conditions for the formation of such precipitates. Unlike bands, homogeneous streaks cannot be separated from the surrounding material.

Spotted horizontal streaks consist of numerous, multi-shaped spots grouped in zones which, owing to their negligible width, cannot be classified as a type of ferruginous horizons (Fig. 6). Like band-like streaks spotted ones are also formed under conditions of a comparatively strong dynamism of the hydrologic factor interrupted by a periodical increase of reduction, a case that is most common in seasonally soaked grounds.

The morphologic difference between band-like and spotted streaks results from a dissimilarity in the extent of the boundary between two opposed oxidation-reduction systems within the reach of influence of the ground-water table upon the soil. Band-like streaks are typical of the deeper lying beds of the soil profile where biologic agents — the plant root system, in particular — do not prevent the formation of a well-marked boundary (between two opposed oxidation-reduction systems), which extends parallel to the ground-water table. If the ground-water table reaches the upward parts of the soil profile where biologic activity is intensive and the soil contains a multitude of various channels which are often directly connected with atmospheric air, a well-defined (running parallel to the ground-water table) continuous boundary separating two opposed oxidation-reduction systems, cannot possibly be formed. A result of such a situation, is the formation of multi--shaped spots instead of streaks within the zone of contact and interaction of reduction and oxidation processes.

## FERRUGINOUS HORIZONS

Ferruginous horizons have, like all the horizons of a soil profile, the appearance of zones running parallel to the ground surface. The development of a large majority of ferruginous horizons is a result of eluvio-illuvial processes which are most conspicuous in grounds that are seasonally either suffused or over-moist (in the upward part of the profile) i.e. pseudo-podzolic and podzolic soils as well as in some black earths and "murshy" sands. Ferruginous horizons range in thickness from 10 to 30—50 cm. If the problem be considered in connection with large geological sections, both the origin and the thickness of these horizons may widely depart from the criteria applied in distinguishing horizons of that type within the soil profile (usually investigated to a depth of 150 cm). An example is the cut through deluvial (colluvial) loess (Pantalowice, Pl. 21) overlying boulder clay which — being hardly pervious — contributed (among other factors) to intensive gleying and mobilization of a large quantity of $Fe^{\cdot\cdot}$ in the bottom part of the loess. All the soluble forms of divalent iron migrated upward to the top of the loess bed, where the degree of oxidation facilitated the conversion of $Fe^{\cdot\cdot}$ to $Fe^{\cdot\cdot\cdot}$, thereby giving the ground its rusty brownish tint. Thus, owing to the fact that the bottom part of the deposit lost much of its iron compounds to the advantage of the upper one, this loess (some 3.5 m in thickness) is divided into two separate horizons: (a) a grey-coloured gleyey-

-eluvial one (with numerous, spherically bedded concretions) and (b) a rusty brownish, gleyey-illuvial one. The illuvial (ferruginous) horizon has some 150 cm in thickness. Hence, from the view-point of soil science it represents a homogeneous parent deposit.

Ferruginous horizons are divided into: (1) homogeneous, (2) spotted, and (3) orstein (iron-pan).

Homogeneous ferruginous horizons represent a higher evolutional stage of homogeneous horizontal streaks. Most of the illuvial horizons of podzols, especially sandy and silty ones belong to this variety (Pl. 20).

If the soil periodically retains an excess of moisture for a relatively long time, the homogeneous ferruginous horizon is gradually dissected by the progressing development of wedges from the gleyey-eluvial zone, which show a well-marked gley colour (Pl. 14).

Spotted horizons are characteristic of formations that are either permanently or seasonally soaked with water and of some with a compact grain-size composition (Pls. 22, 23).

Orstein (iron-pan) horizons widely vary in structure, morphologic features, thickness, degree of cementation and chemical composition. A fundamental common characteristic of all the orstein horizons is the presence of concretional forms of ferruginous precipitates, situated at a well-defined level within the soil profile (Pl. 24). Hence, an orstein horizon may consist of different varieties of homogeneous concretions. A more detailed description of the horizons requires, therefore, a knowledge of the contribution and the nature of the single constituents of a given orstein. Various writers have already emphasized this necessity (Albert, 1910; Bystrov, 1936; Strakhov, 1947, 1960; Russell, 1958; Teischman & Schrödeer, 1954; Polskij, 1961; Schilting, 1963).

## BORDERS

Borders are formed only in cases when a homogeneous ground includes local nests or veins of alien material, differing from it in either grain-size gradation or content of organic matter, such as e.g. sandy nests in silts and boulder clays, lumps of clay, silt and boulder clay or packets of humus in sandy formations. Well--developed borders are most common in various types of re-deformed, alluvial deposits (muds). Formations of that type are (or were once) subjected to gleying or even boggy processes that mobilized large quantities of divalent iron which is readily oxidized at the contact between parent formation and intrusions. Sandy intrusions, particularly veins occurring within more compact deposits have usually a direct contact with oxygen, either atmospheric or dissolved in water.

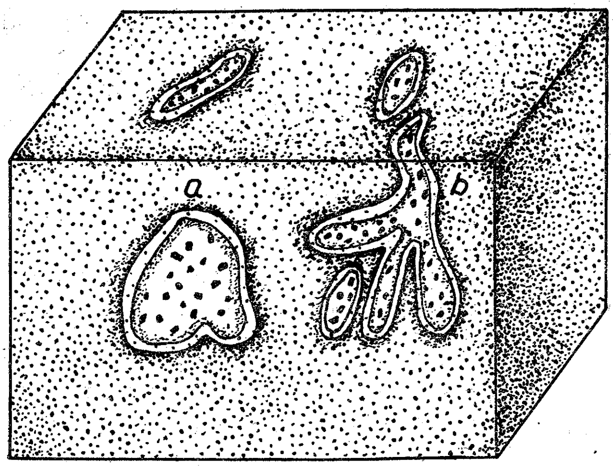


Fig. 7. Borders proper covering a sand nest in a loessy deposit: (a) proper, (b) combined

Such borders, being ferruginous precipitates around the margins, correspond in shape to that of a sandy intrusion situated in a more compact deposit or *vice versa*.

Borders are divided into: (1) borders proper, and (2) combined ones.

Borders proper are formed when the intrusions are not of a combined nature and are clearly discernible from the ground into which they are set (Fig. 7).

Combined borders are typical of vigorously deformed loamy deposits of alluvial origin, containing a multitude of widely dispersed and ramified intrusions (nests and veins) of either loose or slightly clayey sand. The term *ferruginous borders* has but recently been introduced, though the phenomenon itself was often described in the geomorphologic literature, particularly in connection with the study of periglacial involutions. Abundant illustrative examples were presented by Jahn (1951, 1956) in his works dealing with the phenomenon called cylindrical (roller) solifluction. The drawings presented by Jahn (1951), especially figs. 10, 11, and 23 are perfect, and can therefore be referred to as supplementary illustrations. No less interesting are the photographs and drawings in the work by Kozarski and Rotnicki (1964). Some of the illustrations found in the works by: Dylik, Chmielewska and Chmielewski (1954), Sekyra (1956), Tricart (1960), Leckwijck and Macar (1960), Mojski (1961), Olchowik-Kolasińska (1962) and Klatkowa (1965) may also facilitate the identification of ferruginous borders.

These writers hold that the phenomena in question are of the nature of frost-caused deformations formed under periglacial climatic conditions. Although correctly referring to periglacial conditions this view, however, arouses some doubts. To begin with, structural deformations of the ground are of a polygenetic nature. Apart from frost, quite a number of other factors contributed to their formation under periglacial conditions as well as under other geographical latitudes. Let us take as an example the role of the gas-phase which is apt to deform the most perfectly developed deposits, despite their remarkable thickness. Both the scale and the extent of possibilities in that respect depend besides on the origin and the magnitude of the source of gases. Gases may be released by (a) the biochemical decomposition of the organic matter contained in sub-aqueous deposits (muds), (b) plant roots under conditions of excessive moisture or inundation of the ground (bog vegetation, rice cultures, etc.), (c) ground solutions due to rising temperature (gases are much better soluble in cold than in warm water), (d) desiccated grounds during heavier rainfalls when the water percolating into the soil profile rejects into the atmosphere the air stored within the ground, (e) as a result of a raised ground-water table during heavier rainfalls in particular when the surficial soil layers being oversatured prevent the escape of air from below, (f) as a result of changes in atmospheric pressure, etc.

An attempt to elucidate some of the above problems was made by Siuta (1962a, b), and Siuta & Terelak (1963, 1966). Those studies have shown that various ground deformations are recent phenomena. Furthermore, the processes operating to-day are likely to protect some old (Pleistocene periglacial) forms — such as sand-wedges — from being coated with loam.

## HOMOGENEOUS CONCRETIONS

Homogeneous concretions consist of locally grouped and strongly cemented ferruginous precipitates that are easly removable from their matrix and have one feature in common, namely an earthy (homogeneous) inner structure. As homogeneous concretions vary widely in both shape and size, they are subdivided into the following varieties: (1) pepper grains, (2) peas, (3) nuts, (4) bumps, (5) ores.

P e p p e r grains are round ferruginous precipitates, up to 5 mm in diameter. They commonly occur in eluvial horizons of podzolic and pseudo-podzolic soils. Sometimes they are also found in plough or turf-humus horizons. The origin of peppers, like that of the majority of homogeneous concretions, is closely associated with periodical but strong (complete) gleying of the upper soil layers that lasts much longer than the one required for the formation of pseudomycellia.

The presence of peppers indicates that the upper part of the soil profile underwent or still does undergo gleying whose intensity depends on the season, the atmospheric conditions, the way in which the soil is exploited and the agrotechnical methods applied to it. It should be added that some periodically soaked soils of no specified type (e.g. some meadow soils) may also exhibit homogeneous concretions.

In colour, peppers are usually either dark-brown, grey or black. Their colour depends largely on the intensity of periodical gleying in the zone of their occurrence. The darker the concretions, the more intensive was, or is still the process of gleying (S i u t a & G a w ę d a, 1961).

P e a s are larger than pepper grains and range from 5 to 10 mm in diameter. They vary in shape, but generally look like (partly deformed) balls or ellipsoids. Peas occur in the same soils and horizons as pepper grains, but their presence testifies to a much stronger influence of periodical gleying upon modifications in the top part of the soil profile. The presence of peas does not, however, exclude that of other homogeneuos concretions, peppers in particular.

N u t s are the ferruginous concretions, 10—20 mm in diameter of irregular shapes. The occurrence of nuts proves that gleying (either in the past or to-day) has reached a degree of development corresponding to a seasonally marshy soil. Nuts are therefore generally found in soils without any well-developed genetic horizons. Nuts occur in various hydrogenic formations whose water conditions may be already regulated.

As the environment in which they were developed was or still is subjected to intensive reduction, nuts are either dark-gray or black in colour. An exception are the nuts found in sandy soils. These, being less cemented and showing a higher degree of oxidation of the iron compounds are often grey-brownish or even plainly brown.

Peppers, peas and nuts are encountered under various geographic latitudes but are particularly abundant in tropical climatic zones where they are usually much deeper located and generally black in colour (Glinka, 1903; Denisov, 1962; Gorbunov, 1961; Aubert, 1963).

Bumbs are concretions varying 20—50 mm in diameter of the same origin as nuts. Bumps occur in soaked (wet) sands with a shallow ground-water table, containing an abundance of divalent iron compounds. It is most frequently the case in places bordering on marshy areas. Bumps are usually located in the subsurficial soil layer, where — being isolated and loosely connected elements — they built up the orstein (iron-pan) horizon which, though it hampers the development of a root system, does not however prevent the growth of crops and greens.

Ores constitute the most advanced concretions of iron and manganese compounds; a single concretion has more than 50 mm in diameter. In their inner structure, ores differ from all the other homogeneous concretions for they contain a multitude of various channels and hollows, formed as a result of the gradual growth and deformation of the tumour's surface.

## CRUSTY FERRUGINOUS CONCRETIONS

Crusty ferruginous concretions are formed under conditions of intensive and prolonged reduction of the environment that takes place in grounds that are either seasonally or permanently boggy. The formation of crusty concretions requires the presence — within a strongly reduced soil — of channels and hollows (created mainly by the release of biogenic gases) into which oxygen, either dissolved in water or atmospheric, can infiltrate.

The formation of hollows and channels in direct contact with either surface water (if the soil is inundated) or atmosphere is mainly a result of such factors as: (1) the presence of simple associations of organic matter whose decomposition releases large amounts of gases, (2) the compactness and plasticity of the ground which depend on the grain-size gradation and the degree of ground moisture.

Apart from the influence exercised by both these factors on the formation — or the absence — of gas hollows they also determine their shapes, sizes and duration. Best-developed are the gas chambers — generally round or ellipsoidal — (often linked to form a chain) which are formed in stratified silty deposits, that are rich in organic matter and lie at the bottom of shallow water basins. Forms of that type were described in some detail by Siuta and Motowicka (1963) and Siuta and Rejman (1963). The presence of well-developed crusty concretions indicates that at the time of their formation the ground was submerged and the ground environment was strongly reduced owing to the presence of a large amount of organic matter (within a given sediment).

Crusty concretions are divided according to shape into: (1) tube-like, (2) bubble-like, (3) pear-like, and (4) ball ones.

Tube-like crusty concretions are commonly found in alluvial soils (Pl. 29) in which the influence of boggy processes is well-marked (Siuta, 1960). The presence of tubes affords, of course no evidence of any actual defficiency in the present-day system of air-water conditions. Boggy processes whose operations and degree of intensity can be inferred from the corresponding forms of ferruginous precipitates — may have receded a long time ago. Such an evidence (traces) is a vital point in the study of the origin and the evolution of alluvial soils. Apart from well-developed and readily removable tubes, there exist also less cemented ferruginous precipitates, that are located on the surface of soil channels. Precipitates of that type which are reminiscent of efflorescences have not been singled out as a separate variety, but are considered to belong to the type of hollow-efflorescences. Tubes are also found in all the other silty or clayey deposits that exhibit other varieties of crusty concretions. They usually connect these varieties with the overlying water or the atmosphere and link the individual balls to one another. Tube-like crusty concretions occur in mineral marshy soils under various geographical latitudes, in particular tropical ones (Glinka, 1903).

B u b b l e - l i k e c r u s t y c o n c r e t i o n s represent a transitional form from efflorescences in small, gas-produced hollows and homogeneous concretions of lesser sizes (peas and nuts). Bubbles can be extracted only if wet; dry ones can instead be easily crushed as they are hollow and the crust is porous (Pl. 30).

P e a r - l i k e c r u s t y c o n c r e t i o n s are usually the deepest-reaching end parts of vertically set crusty concretions, those in particular that are linked to form round chains sometimes also the end parts of tubes (Pl. 31).

B a l l - l i k e c r u s t y c o n c r e t i o n s differ from the pear-like ones by a more oval shape and two tube-like apertures in the inner hollow. If the layer is disturbed by water in the site of occurrence of the crusty concretions, the hollows are filled with the surrounding material. In a previous work, the phenomenon was discussed in detail (S i u t a & M o t o w i c k a, 1963).

## SPHERICALLY BEDDED CONCRETIONS

Spherically bedded concretions are of the same origin as the crusty ones (Pl. 37). The only difference consists in that the crusty concretions form only one strongly cemented layer of ferruginous precipitates (a crust), while spherically bedded ones consist of several rings, concentrically encircling the channels and hollows i. e. the routes of oxygen infiltration from the atmosphere.

This structural difference results from a difference in the dynamics of the hydrologic factor. Crusty concretions are — as mentioned above — formed under persistently boggy conditions, while atmospheric oxygen (generally through water) fails to infiltrate any farther than to the walls of the hollows and channels, produced by the escape of biogenic gases from the ground.

Spherically bedded concretions may be initially formed in permanently submerged grounds but the development of further rings is determined by the seasonal alternation of drainage and excessive moisture (even inundation). In other words, the formation of spherically bedded concretions is attributable to the period of gradual recession of the boggy processes (S i u t a & M o t o w i c k a, 1963).

A typical feature of all the spherically bedded concretions is that — if well-developed — each ring may be separated from the outer zones, a circumstance facilitating extraction of a whole concretion, as well as of each single rings.

From the concentric ring pattern formed by these concretions various writers have inferred that they originated around tree-roots. This view was set forth by Frosterus (1913). He however failed to notice that well-developed precipitates of that type occur in strongly reduced grounds that lack the conditions required for the development of strike tree roots.

Descriptions of spherically bedded concretions were presented by the following writers: Jahn (1951) in discussing roller solifluction, mentions the presence of spindle-like forms, Olchowik-Kolasińska (1955) cites examples of spindle-like forms due to solifluction, Klatka (1955) discusses limonite concretions composed of concentrically bedded ferruginous crusts occurring in the bottom part of loess in the foreground of the Łysogóry Mts.; Halicki (1961) found concretions of that type in boulder clay; Denisov (1962) reports the presence of spherically bedded concretions from the laterites of Congo.

Spherically bedded concretions are sub-divided into five varieties: (1) cylindrical, (2) finger-like, (3) pear-like, (4) round, (5) ball-like chains.

Cylindrical spherically bedded concretions are formed around vertical tubes, and are therefore similar to tube-like crusty concretions (Pls. 32, 33).

Finger-like spherically bedded concretions, developed around tubes, are ramified to form something like two or several fingers usually extending from one and the same pear-like hollow (Fig. 8).

Pear-like spherically bedded concretions are analogous with the same variety of crusty concretions (Pl. 34).

Spherically bedded round concretions are analogous with the same variety of crusty concretions. By removing all the successive rings it is possible to reach the crust that shelters the air chamber. If the crust is well-developed, the extracted element gains the appearance of a crust concretion (Pl. 35).

Spherically bedded ball-like chains are encountered in strongly reduced and thick water-laid silt deposits, showing a faintly stratified pattern (Pl. 36). Deposits of that type

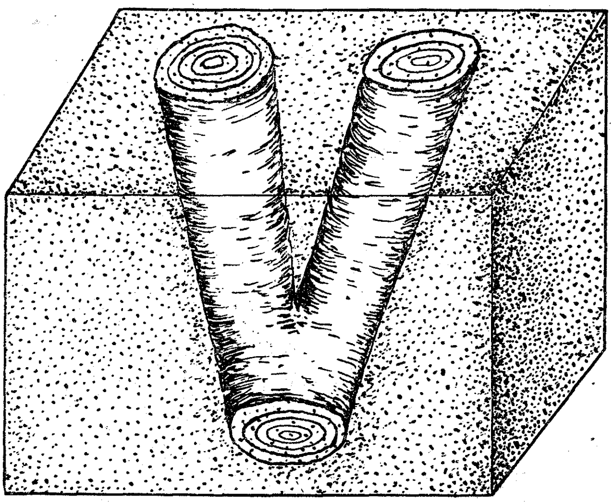

Fig. 8. Spherically-bedded finger-like concretions

afford suitable conditions for the formation of a whole number of gas chambers that are oriented vertically (super-imposed) and connected all along by one passage which (during the formation of the concrections) is in direct contact with either atmosphere or surface water (flood).

### SMALL PLATES

Small plates may — like all the other concretional forms of ferruginous precipitates — be easily separated from their matrix. They exhibit two varieties, namely: (1) contact plates, and (2) fissure plates.

C o n t a c t s m a l l p l a t e s (Pls. 16, 38) commonly occur in deluvial (colluvial) loesses especially if the loess — with an abundance of organic matter — is deposited on proper loess of a yellow colour i.e. one that does not show any conspicuous traces of under-oxidation. Phenomena of that type occurring in loess are being erroneously interpreted as genetic fossil soil horizons. The presence of a well-developed plate of ferruginous precipitates located below a strongly reduced deluvial (colluvial) loess-layer clearly indicates that the site upon which the deluvial loess accumulated was previously so severely eroded as to be devoid of a humus horizon. The organic matter contained in the sub-deluvial loess layer prevents the development of a well-marked streak, the more so that of a plate (or plates) of contact of ferruginous precipitates. The above sequence of washing away the substratum and of a re-accumulation of deluvial (colluvial) loess is the rule, even under present-day conditions, usually during certain early-spring seasons (favouring slope slides).

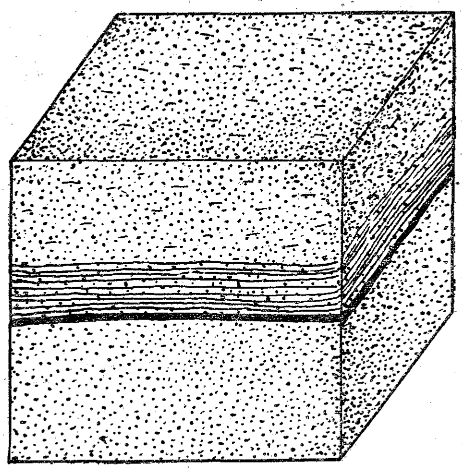

Fig. 9. Small contact plate developed on the border of deluvial loess strongly gleyed with underlying yellow proper loess

Contact small plates may also form when the loess rests on well-drained sands. In such cases, the infiltrating iron compounds are being oxidized at the contact of loess and sands; but then the ferruginous precipitates fail to show a well-defined plate-like shape. Such a type has been formerly defined as *contact ferruginous precipitates* (S i u t a, 1960). Precipitates that are irregularly shaped and composed of many crusty shales may be defined as combined contact plates. The latter are not uncommon in the sub-surface horizons of sandy soils with vertically differentiated grain-size gradations where they inhibit the percolation of water and may thus be responsible for intensive erosion during rain showers (Pl. 39). Illustrations of such ferruginous precipitates were presented by J a h n (1956, p. 176, pl. 1 and 2).

F i s s u r e s m a l l p l a t e s are rather rare. They are formed during the recession of boggy processes and the cracking of the strongly reduced fine-grained loams. Such plates mark, therefore, a further stage in the cummulation and concentration of fissure efflorescences. Well-developed fissure plates can be formed and preserved over longer periods within deeper lying horizons alone. A high frequency of alternating suffusion and desiccation of the ground with thermal changes prevent the formation of fissure plates within the top soil layers.

The above classification of ferruginous precipitates does not include any of the older, chiefly limonite-siderite (iron-ores) and siderite concretions that were formed in pre-Tertiary times. These forms were deliberately left aside for — in our opinion — their genesis has not been hitherto satistactorily accounted for and our own investigations do not as yet allow of a well-founded interpretation.

## FERRUGINOUS PRECIPITATES AS INDICATORS OF AIR-WATER CONDITIONS IN SOIL

Each of the forms and varieties of ferruginous precipitates is typical of a specific system of air-water conditions within the soil. As this system varies according to seasons, even gley spots are absent during a dry summer from formations which during a wet spring underwent intensive reduction. Gleying is relatively promptly stopped (in the upper part of the soil profile) but the ferruginous precipitates that were formed in this period constitute a record of already non-existant previous air-water conditions which shall be defined as: *oxidation-reduction* (*gley*) *states of the ground.*

In determining the oxidation-reduction states of the ground, the following parameters shall be considered: (a) grain-size gradation of the deposit (I—V), (b) depth of its occurrence in the soil profile (a, b, c), (c) hydrologic type of the ground environment (A, B, ...H), (d) form of gleying (a, b, ...f), and (e) the time of its duration (+, ++, +++).

These parameters are presented in table II, according to which the oxidation-reduction (gley) states, that are typical of all the unified (either uniform or similar grain-size gradations) were recorded. Each of the "states" distinguished is marked by a separate symbol, revealing the nature of each of the parameters ennumerated above.

A full list of the "states" distinguished, with ennumeration of the correlative forms of ferruginous precipitates is presented in table III. This table is intended to supplement the description of

Table III

Oxidation-reduction states of ground environment and varieties of corresponding ferruginous precipitates

| State of ground environment | | Forms of ferruginous precipitates |
|---|---|---|
| No. | Symbol | |
| 1 | Ic $Ab^{+}$ | dissolution spots (5) * |
| 2 | Ic $Ac^{+}$ | dissolution spots (5) |
| 3 | Ia $Ba^{+}$ | dissolution spots (5) |
| 4 | Ia $Ba^{+}$ | dissolution spots (5) |
| 5 | Ib $Ba^{+}$ | dissolution spots (5) |
| 6 | Ib $Bb^{+}$ | dissolution spots (5) |
| 7 | Ib $Bc^{+}$ | dissolution spots (5) |
| 8 | Ib $Bc^{+}$ | nest coatings (10), dissolution spots (5) |
| 9 | Ic $Bb^{++}$ | dissolution (5) and concentric (4) spots |
| 10 | Ic $Bc^{++}$ | horizontal spotted streaks (17), concentric spots (4) |
| 11 | Ia $Db^{++}$ | dissolution (5) and concentric (4) spots, surface efflorescences (1) |
| 12 | Ia $Dc^{+}$ | dissolution (5) and concentric (4) spots, pseudomycellia (8), surface efflorescences (1) |
| 13 | Ib $Dc^{++}$ | dissolution spots (5), horizontal spotted streaks (17) |
| 14 | Ib $Dd^{+}$ | horizontal band-like (17) and spotted (15) streaks |
| 15 | Ic $Dd^{++}$ | horizontal band-like (17) and spotted (15) streaks |
| 16 | Ia $Ec^{+++}$ | dissolution (5) and concentric (4) spots, horizontal spotted streaks (15), pseudomycellia (8), surface efflorescences (1) |
| 17 | Ia $Ed^{+}$ | pseudomycellia (8), concentric (4) and dissolution (5) spots, surface efflorescences (1) |
| 18 | Ib $Ed^{++}$ | horizontal band-like streaks (15), concentric (4) and dissolution (5) spots |
| 19 | Ic $Ed^{+++}$ | concentric spots (4) (in small quantities) |
| 20 | Ia $Fd^{++}$ | concentric spots (4) |
| 21 | Ib $Fd^{+++}$ | ferruginous precipitates do not form (0) |
| 22 | Ic $Fd^{+++}$ | ferruginous precipitates do not form (0) |
| 23 | Ia $Gd^{+++}$ | ferruginous precipitates do not form (0) |
| 24 | Ibc $Gd^{+++}$ | ferruginous precipitates do not form (0) |
| 25 | Ia, b, c $Hd^{+++}$ | ferruginous precipitates do not form (0) |
| 26 | IIc $Aa^{+}$ | dissolution spots (5) |
| 27 | IIa $Ba^{+}$ | dissolution spots (5) |
| 28 | IIa $Be^{+}$ | dissolution spots (5) |
| 29 | IIb $Be^{+}$ | nest coatings (10), dissolution spots (5) |
| 30 | IIc $Bb^{+}$ | dissolution spots (5) |
| 31 | IIc $Bc^{+}$ | dissolution (5) and concentric (4) spots |
| 32 | IIa $Db^{+++}$ | dissolution (5) and concentric (4) spots, surface efflorescences (1) |

(cont.)

| State of ground environment | | Forms of ferruginous precipitates |
|---|---|---|
| No. | Symbol | |
| 33 | IIa Dc+ | dissolution (5) and concentric (4) spots, pseudomycellia (8), surface efflorescences (1) |
| 34 | IIb Dc+++ | horizontal spotted streaks (17), dissolution spots (5) |
| 35 | IIb Dd+ | horizontal spotted (17) and band-like (15) streaks, concentric (4) and dissolution (5) spots |
| 36 | IIc Dd++ | horizontal spotted streaks (17), concentric (4) and dissolution (5) spots |
| 37 | IIa Ec+++ | dissolution (5) and concentric (4) spots, surface efflorescences (1) |
| 38 | IIa Ed+ | concentric (4) and dissolution (5) spots, pseudomycellia (8), surface efflorescences (1) |
| 39 | IIb Ed++ | concentric spots (4) |
| 40 | IIc Ed+++ | absence of ferruginous precipitates (0) |
| 41 | IIa Fd++ | concentric spots (4) |
| 42 | IIb, c, Fd+++ | ferruginous precipitates do not form (0) |
| 43 | IIa, b, c Gd+++ | ferruginous precipitates do not form (0) |
| 44 | IIa, b, c Hd+++ | ferruginous precipitates do not form (0) |
| 45 | IIIa Ba+ | dissolution spots (5) |
| 46 | IIIa Be+ | nest coatings (10), dissolution (5) and concentric (4) spots |
| 47 | IIIa Bf+ | dissolution (5) and concentric (4) spots |
| 48 | IIIb Ba+ | dissolution spots (5) |
| 49 | IIIb Be+ | vertical (9) and nest (10) coatings |
| 50 | IIIb Bf+ | dissolution (5) and concentric (4) spots |
| 51 | IIIc Bb+ | dissolution spots (5) |
| 52 | IIIc Bf+ | dissolution spots (5) |
| 53 | IIIa Ca+++ | dissolution (5) and concentric (4) spots, surface efflorescences (1) |
| 54 | IIIa Cb+ | dissolution (5) and concentric (4) spots, surface efflorescences (1) |
| 55 | IIIa Cc+ | concentric spots (4), pseudomycellia (8), homogeneous concretions (23), surface efflorescences (1) |
| 56 | IIIa Ce++ | nest coatings (10), dissolution (5) and concentric (4) spots |
| 57 | IIIb Cd++ | dissolution (5) and concentric (4) spots |
| 58 | IIIb Cc+ | dissolution (5) and concentric (4) spots |
| 59 | IIIb Ce+ | vertical (9) and nest (10) coatings |
| 60 | IIIb Cf++ | vertical fissure streaks (11), dissolution (5) and concentric (4) spots |
| 61 | IIIc Ce+ | vertical coatings (9) |
| 62 | IIIc Cf+ | vertical fissure streaks (11), dissolution spots (5) |

(cont.)

| State of ground environment | | Forms of ferruginous precipitates |
|---|---|---|
| No. | Symbol | |
| 63 | IIIa Db+++ | dissolution (5) and concentric (4) spots, surface efflorescences (1) |
| 64 | IIIa Dc++ | dissolution (5) and concentric (4) spots, pseudomycellia (8), homogeneous concretions (23), surface efflorescences (1) |
| 65 | IIIb Dc+++ | concentric (4) and dissolution spots (5) |
| 66 | IIIb Dd+ | concentric (4) and dissolution spots (5) |
| 67 | IIIc Dd++ | concentric spots (4) (in small quantities) |
| 68 | IIIa Ec+++ | dissolution (5) and concentric (4) spots, surface efflorescences (1), homogeneous concretions (23) |
| 69 | IIIa Ed+ | pseudomycellia (8), concentric spots (4), homogeneous concretions (23), surface efflorescences (1) |
| 70 | IIIb Ed++ | concentric spots (4), crusty tube-like concretions (28) |
| 71 | IIIc Ed+++ | crusty tube-like concretions (28) |
| 72 | IIIa Fd++ | crack efflorescences (2), seepage spots (6), pseudomycellia (8), borders (21) |
| 73 | IIIb, c, Fd+++ | crusty concretions (28), (mostly tube-like) |
| 74 | IIIa, b, c Gd+++ | non-existant ferruginous concretions (0) |
| 75 | IIIa, b, c Hd+++ | crusty tube-like concretions (28) (they appear very rarely) |
| 76 | IVa Ba++ | dissolution spots (5) |
| 77 | IVa Bb+ | dissolution (5) and concentric (4) spots |
| 78 | IVb Be+ | nest coatings (10), dissolution (5) and concentric (4) spots |
| 79 | IVb Bf++ | vertical fissure streaks (11) |
| 80 | IVc Bf++ | vertical fissure streaks (11), dissolution spots (5) |
| 81 | IVa Cb++ | dissolution (5), concentric (4) and fissure-network (7) |
| 82 | IVa Cc+ | cencentric (4) and fissure-network (7) spots |
| 83 | IVa Ce+ | nest coatings (10), dissolution (5) and concentric (4) spots |
| 84 | IVb Ce++ | crack efflorescences (2), fissure-network (7) and dissolution (5) spots |
| 85 | IVb Cf++ | vertical fissure streaks (11), dissolution spots (5) |
| 86 | IVc Cf+ | vertical fissure streaks (11) |
| 87 | IVa Db+++ | dissolution (5) and concentric (4) spots, homogenous concretons (23), surface efflorescences (1) |
| 88 | IVa Dc++ | concentric (4) and dissolution (5) spots |
| 89 | IVa Dd+ | concentric (4) and dissolution (5) spots, pseudomycellia (8), homogeneous concretions (23) |
| 90 | IVb Dc+++ | dissolution (5) and concentric (4) spots |

(cont.)

| State of ground environment | | Forms of ferruginous precipitates |
|---|---|---|
| No. | Symbol | |
| 91 | IVb $Dd^{+}$ | dissolution (5) and concentric (4) spots, seepage spots (6), borders (21) |
| 92 | IVc $Dd^{++}$ | concentric (4) and fissure-network (7) spots, borders (21) |
| 93 | IVa $Ec^{+++}$ | dissolution (5) and concentric (4) spots, homogeneous concretions (23) |
| 94 | IVa $Ed^{+}$ | concentric (4) and fissure-network (7) spots, pseudomycellia (8), homogeneous concretions (23) |
| 95 | IVb $Ed^{++}$ | concentric (4) and fissure-network (7) spots, crusty tube-like concretions (28), borders (21) |
| 96 | IVc $Ed^{+++}$ | crusty tube-like concretions (28), borders (21) |
| 97 | IVa $Fd^{++}$ | crack efflorescences (2), seepage spots (6), pseudomycellia (8), borders (21) |
| 98 | IVb, c $Fd^{+++}$ | crusty tube-like concretions (28) |
| 99 | IVa, b, c $Gd^{+++}$ | non-existant ferruginous precipitates (0) |
| 100 | IVa, b, c $Hd^{+++}$ | non-existant ferruginous precipitates (0) |
| 101 | Va $Ba^{+}$ | dissolution spots (5) |
| 102 | Va $Be^{+}$ | nest coatings (10) |
| 103 | Vb $Ba^{+}$ | dissolution spots (5) |
| 104 | Vb $Be^{+}$ | vertical (9) and nest (10) coatings |
| 105 | Vc $Be^{+}$ | vertical coatings (9) |
| 106 | Va $Cb^{++}$ | dissolution (5) and concentric (4) spots, surface efflorescences (1) |
| 107 | Va $Cc^{+}$ | pseudomycellia (8), concentric (4) and dissolution (5) spots, homogeneous concretions (23), surface efflorescences (1) nest coatings (10) |
| 108 | Va $Ce^{+}$ | nest coatings (10) |
| 109 | Va $Cf^{+}$ | dissolution (5) and concentric (4) spots |
| 110 | Vb $Cb^{++}$ | dissolution spots (5) |
| 111 | Vb $Cc^{+}$ | concentric spots (4), horizontal spotted streaks (17), homogeneous conjcrections (23) |
| 112 | Vb $Cf^{++}$ | vertical fissure streaks (11), dissolution (5) and concentric (4) spots |
| 113 | Vc $Cf^{+}$ | vertical fissure streaks (11) |
| 114 | Va $Db^{+++}$ | dissolution (5) and concentric (4) spots, surface efflorescences (1) |
| 115 | Va $Dc^{++}$ | pseudomycellia (8), concentric spots (4) homogeneous concretions (23), surface efflorescences (1) |
| 116 | Vb $Dc^{+++}$ | dissolution (5) and concentric (4) spots |
| 117 | Vb $Dd^{+}$ | pseudomycellia (8), concentric spots (4), horizontal spotted streaks (17), homogeneous concretions (23), borders (21) |

(cont.)

| State of ground environment No. | Symbol | Forms of ferruginous precipitates |
|---|---|---|
| 118 | Vc Dd++ | dissolution (5) and concentric (4) spots, spherically bedded concretions (32), borders (21) |
| 119 | Va Ec+++ | pseudomycellia (8), concentric (4) and dissolution (5) spots, homogeneous concretions (23), surface efflorescences (1) |
| 120 | Va Ed+ | pseudomycellia (8), concentric spots (4), crusty bubble-like concretions (29), sufrace efflorescences (1) |
| 121 | Vb Ed++ | concentric spots (4), horizontal spotted streaks (17), crusty tube-like concretions (28), spherically bedded concretions (32) |
| 122 | Vc Ed+++ | crusty concretions (28), borders (21), spherically bedded concretions (32) |
| 123 | Va Fd++ | pseudomycellia (8), crusty tube-like concretions (28), seepage spots (6), crack efflorescences (2) |
| 124 | Vb, c Fd+++ | crusty concretions: small tube-like (28), small bubble-like (29), pear-like (30), and ball-like (31); and spherically bedded concretions: cylindrical (32), finger-like (33), pear-like (34), round (35), and ball-like chains (36) |
| 125 | Va, b, c Gd+++ | the same forms of the ferruginous precipitates as under no. 124 (Vb, c, Fd+++). These forms appear very rarely because murshy plants prevent the infiltration of oxygen into the ground (28, 29, 30, 31, 32, 33, 34, 35, 36) |
| 126 | Va, b, c Hd+++ | crusty shperically bedded concretions (all varieties) develop here when water is shallow (28, 29, 30, 31, 32, 33, 34, 35, 36) |

* Figures in parenthesis are the numbers of the varieties of ferruginous precipitates.

the individual environments within which the forms and varieties of ferruginous precipitates are likely to occur. A diagrammatic presentation of the oxidation-reduction states of the ground environment facilitates a concise and comprehensible description of the single forms and varieties of ferruginous precipitates and — at the same time — an amplification of the problem by additional detailed information concerning the origin and occurrence of each particular phenomenon.

It should be added that table III is an analytical one. Each of the single phenomena (forms) of gleying together with the associated (derived) forms and varieties of ferruginous precipitates are here viewed separately. Table III contains, therefore, no synthetic presentation of the totality of ferruginous precipitates (formed under the action of various oxidation-reduction states) that are located in each of the single horizons as well as in the whole soil profile. A synthetic presentation of that type is shown in table IV, which illustrates the formation of the single varieties of ferruginous precipitates on the background of the hydrologic types of the ground environment — as presented in table II.

In other words, table IV constitutes a record of all the varieties of ferruginous precipitates produced by the combined action of gleying within various types of hydrologic ground environment. Confrontation of tables IV and II shows that identical forms and gleying states occurring within the same grain-size group may often produce dissimilar varieties of ferruginous precipitates. The difference, in both the quality and the quantity of various ferruginous precipitates depends just as much on the hydrologic type as on the depth of the soil profile. In boggy grounds, ferruginous precipitates do not, or hardly ever, occur while in submerged ones (if these are devoid of a dense vegetation cover) showing an analogous grain-size gradation (e. g. in dusty loams) various crusty concretions are formed, also spherically bedded ones.

In using table IV one should remember that the varieties listed in it may but must not necessarily occur jointly in every one system of a definite hydrologic type. On the other hand, some other related varieties may occur, in particular those belonging to the same form-type. An example of it may be the different varieties of homogeneous concretions which are characteristic of identical air-water system. The varieties of homogeneous concretions, growing gradually from pepper grains to nuts and bumps, merely provide evidence of an increased recurrence and persistence of the effects of over-saturation or intensive reduction of the ground environment.

In order to provide a possibility of using ferruginous precipitates as indicators facilitating an identification of various systems of air-water conditions within soils and to illustrate them in the form of symbols a "key to the definitions of the types of hydrologic ground environment" has been worked out and the data obtained are presented in table V. This table shows that a definition of the hydrologic type of a ground environment requires information gained in the field with regard to the following questions: (1) grain--size gradation (grain-size group I—V) and depth of the soil profile (a); (2) varieties of ferruginous precipitates at various levels of the soil profile (1, 2, 5, 8, etc.). From the ferruginous precipitates, occurring in any one grain-size group and profile level, the form and state of gleying are determined which indicate the corresponding type of hydrologic environment.

If the totality of field observations be expressed in symbols, the result will be as follows:

(a) slightly clayey sand (I) containing at 40 (50) cm depth (a) seepage spots (5) and concentric ones (4), pseudomycellia (8) and surface efflorescences (1) form a total symbol: I a, 5, 4, 8, 1;

(b) silty deposits (V) containing at a depth of down to 40 (50) cm (a) pseudomycellia (8), concentric spots (4), seepage spots (5), homogeneous concretions (23), surface efflorescences (1) form a total symbol: V a, 8, 4, 5, 23, 1.

Ferruginous precipitates at depths of 0—40 (50) cm were formed depending on the grain-size group under the influence of the following forms and states of gleying:

(a) I a, 5, 4, 8, 1 — owing to a short period of zonal gleying ($c^+$) that takes place in periodically soaked grounds (D);

(b) V a, 8, 4, 5, 23, 1 — owing to a short period of zonal gleying ($c^+$) that takes place in periodically over-moist grounds (C).

Thus, with the help of an overall symbol of the field observations one can easily determine the form and the state of soil gleying as well as the type of hydrologic environment:

(a) I a, 5, 4, 8, 1 — $c^+$D,

(b) V a, 8, 4, 5, 23, 1 — $c^+$C.

As a determination of the grain-size gradation (group) and of the depth of the soil layer in question do not present any difficulties, the ability to identify correctly the individual varieties of ferruginous precipitates occurring in the soil profile provides additional and relevent evidence concerning the air-water properties of the soil.

A confrontation of the results obtained in the field with the data presented in table V may enable one to establish the hydrologic type as well as the form and state of gleying of the soil, those forms of gleying in particular that are merely periodical. For, such forms though they occur only in the summer and are hardly discernible often constitute a decisive factor of fertility and agricultural productivity of the soil.

The combined character of the overall symbols in table V may largely handicap an exhaustive presentation of the increasing

Table IV

Scheme of appearance of ferruginous precipitates (varieties) in various hydrological ground environments

| Textural group | | Depth in cm | Types of hydrological ground environments A—H and varieties of the corresponding ferruginous precipitates (1, 2, 4) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | A | B | C | D | E | F | G | H |
| | | | Dry grounds | Grounds with optimal water conditions | Periodically over-moist grounds | Periodically soaked grounds | Permanently soaked grounds | Periodically marshy grounds | Boggy grounds | Submerged grounds (slimes) |
| I | a | 0—40(50) | non-existant | 5 | | 1, 4, 5, 8 | 1, 4, 5, 8, 15 | 4 | non-existant | non-existant |
| | b | 40(50)—80 | non-existant | 5, 10 | | 5, 15, 17 | 4, 5, 15 | non-existant | non-existant | non-existant |
| | c | 80—120 | 5 | 4, 5, 17 | | 4, 5, 13, 15, 17 | 4 | non-existant | non-existant | non-existant |
| II | a | 0—40(50) | non-existant | 5 | | 1, 4, 5, 8 | 1, 4, 5, 8 | 4 | non-existant | non-existant |
| | b | 40(50)—80 | non-existant | 5, 10 | | 4, 5, 15, 17 | 4 | non-existant | non-existant | non-existant |
| | c | 80—120 | | 4, 5 | | 4, 5, 17 | non-existant | non-existant | non-existant | non-existant |
| III | a | 0—40(50) | | 4, 5, 10 | 1, 4, 5, 8, 10, 23 | 1, 4, 5, 8, 23 | 1, 4, 5, 8, 23, 28 | 2, 6, 8, 21 | non-existant | 28 |
| | b | 40(50)—80 | | 4, 5, 9, 10 | 4, 5, 9, 10, 11 | 4, 5 | 4, 28 | 28 | non-existant | 28 |
| | c | 80—120 | | 5 | 5, 9, 11 | 4 | 28 | 28 | non-existant | 28 |
| IV | a | 0—40(50) | | 4, 5 | 4, 5, 7, 10 | 1, 4, 5, 8, 23 | 4, 5, 8, 23 | 2, 6, 8, 21 | non-existant | non-existant |
| | b | 40(50)—80 | | 4, 5, 10, 11 | 2, 5, 11 | 4, 5, 6, 21 | 4, 7, 21, 28 | 28 | non-existant | non-existant |
| | c | 80—120 | | 5, 11 | 11 | 4, 7, 21 | 21, 28 | non-existant | non-existant | non-existant |
| V | a | 0—40(50) | | 5, 10 | 1, 4, 5, 8, 10, 23 | 1, 4, 5, 8, 17, 21, 23 | 1, 4, 5, 8, 29 | 2, 6, 8, 28 | almost non-existant | 28, 29, 30, 31, 32, 33, 34, 35, 36 |
| | b | 40(50)—80 | | 9, 10 | 4, 5, 11, 17, 23 | 4, 5, 8, 17, 21, 23 | 4, 17, 28, 32 | 28, 29, 30, 31, 32, 33, 34, 35, 36 | almost non-existant | 28, 29, 30, 31, 32, 33, 34, 35, 36 |
| | c | 80—120 | | 9 | 11 | 4, 5, 21, 32 | 21, 28, 32 | 28, 29, 30, 31, 32, 33, 34, 35, 36 | almost non-existant | 28, 29, 30, 31, 32, 33, 34, 35, 36 |

Table V

The key for identification of hydrological ground environment on the basis of ferruginous precipitates

| Identification in the field | | | Identification in the laboratory | | Identification symbols | | |
|---|---|---|---|---|---|---|---|
| No. | Textural groups | Variety of ferruginous precipitates | Forms and states of gley | Types of hydrological ground environment | In the field | In the laboratory | |
| 1 | Ia | 5 | spotted$^{+}$, local$^{+}$ | B | Ia, 5 | $a^{+}$, $e^{+}$ | B |
| 2 | Ia | 5, 4, 1 | marbled$^{++}$ | D | Id, 5, 4, 1 | $b^{++}$ | D |
| 3 | Ia | 5, 4, 8, 1 | zonal$^{+}$ | D | Ia, 5, 4, 8, 1 | $c^{++}$ | D |
| 4 | Ia | 5, 4, 15, 8, 1 | zonal$^{+++}$, complete$^{+}$ | E | Ia, 5, 4, 15, 8, 1 | $c^{+++}$, $d^{+}$ | E |
| 5 | Ia | 4 | complete$^{++}$ | F | Ia, 4 | $d^{++}$ | F |
| 6 | Ia | 5 | spotted$^{+}$, marbled$^{++}$ | B | Ib, 5 | $a^{+}$, $b^{+}$ | B |
| 7 | Ib | 5, 10 | zonal$^{+}$, local$^{+}$ | B | Ib, 5, 10 | $c^{+++}$, $e^{+}$ | B |
| 8 | Ib | 5, 17 | zonal$^{++}$ | D | Ib, 5, 17 | $c^{++}$ | D |
| 9 | Ib | 17, 15 | complete$^{+}$ | D | Ib, 17, 15 | $d^{+}$ | D |
| 10 | Ib | 15, 4, 5 | complete$^{++}$ | E | Ib, 15, 4, 5 | $a^{++}$ | E |
| 11 | Ic | 5 | marbled$^{+}$, zonal$^{+}$ | A | Ic, 5 | $b^{+}$, $c^{+}$ | A |
| 12 | Ic | 5, 4, 17 | complete$^{++}$ | B | Ic, 5, 4, 17 | $b^{++}$, $c^{++}$ | B |
| 13 | Ic | 17, 15, 13, 4, 5 | spotted$^{+}$, local$^{+}$ | D | Ic, 17, 15, 4, 5 | $d^{++}$ | D |
| 14 | IIa | 5 | marbled$^{+++}$, zonal$^{+}$ | B | IIa, 5 | $a^{+}$, $e^{+}$ | B |
| 15 | IIa | 5, 4, 1 | zonal$^{+++}$, complete$^{+}$ | D | IIa, 5, 4, 1, 8 | $b^{++}$, $c^{+}$ | D |
| 16 | IIa | 5, 4, 1, 8 | complete$^{++}$ | E | IIa, 5, 4, 1, 8 | $c^{+++}$, $a^{+}$ | E |
| 17 | IIa | 4 | local$^{+}$ | F | IIa, 4 | $d^{++}$ | F |
| 18 | IIb | 10, 5 | zonal$^{+++}$, complete$^{++}$ | B | IIb, 10, 5 | $a^{+}$ | B |
| 19 | IIb | 17, 15, 5. 4 | complete$^{++}$ | D | IIb, 17, 15, 5, 4 | $c^{+++}$, $d^{+}$ | D |
| 20 | IIb | 4 | spotted$^{+}$ | E | IIb, 4 | $d^{++}$ | E |
| 21 | IIc | 5 | zonal$^{+}$ | A | IIc, 5 | $a^{+}$ | A |
| 22 | IIc | 5, 4 | complete$^{++}$ | B | IIc, 5, 4 | $c^{+}$ | B |
| 23 | IIc | 17, 4, 5 | spotted$^{+}$ | D | IIc, 17, 4, 5 | $d^{++}$ | D |
| 24 | IIIa | 5 | local$^{+}$ | B | IIId, 5 | $a^{+}$ | B |
| 25 | IIIa | 10, 5 | seepage$^{+}$ | B | IIIa, 10, 5 | $e^{+}$ | B |
| 26 | IIIa | 5, 4 | spotted$^{+++}$, marbled$^{+}$ | B | IIIa, 5, 4 | $f^{+}$ | B |
| 27 | IIIa | 5, 4, 1 | zonal$^{+}$ | C | IIIa, 5, 4, 1 | $a^{+++}$, $d^{+}$ | C |
| 28 | IIIa | 4, 1, | local$^{+}$ | C | IIIa, 4, 1 | $c^{+}$ | C |
| 29 | IIIa | 10, 5, 4 | zonal$^{++}$ | C | IIIa, 10, 5, 4 | $e^{+}$ | C |
| 30 | IIIa | 5, 4, 23, 1 | zonal$^{+++}$, complete$^{+}$ | D | IIIa, 5, 4, 23, 1 | $c^{++}$ | D |
| 31 | IIIa | 5, 4, 23, 1 | complete$^{++}$ | E | IIIa, 5, 4, 23, 1 | $c^{+++}$, $d^{+}$ | E |
| 32 | IIIa | 2, 6, 8, 21 | spotted$^{+}$ | F | IIIa, 2, 6, 8, 21 | $d^{++}$ | F |
| 33 | IIIb | 5 | local$^{+}$ | B | IIIb, 5 | $a^{+}$ | B |
| 34 | IIIb | 9, 10, 5 | spotted$^{+}$, zonal$^{+}$ | B | IIIb, 2, 6, 8, 21 | $e^{+}$ | B |
| 35 | IIIb | 5, 4 | seepage$^{+}$ | C | IIIb, 5, 4 | $a^{++}$, $c^{+}$ | C |
| 36 | IIIb | 11, 5, 4 | zonal$^{+++}$, complete$^{+}$ | C | IIIb, 11, 5, 4 | $f^{+}$ | C |
| 37 | IIIb | 4 | complete$^{++}$ | D | IIIb, 4, 28 | $c^{+++}$, $d^{+}$ | D |
| 38 | IIIb | 4, 28 | marbled$^{++}$, seepage$^{+}$ | E | IIIb, 4 | $d^{++}$ | E |
| 39 | IIIc | 5 | local$^{+}$, seepage$^{+}$ | B | IIIc, 5 | $b^{++}$, $f^{+}$ | B |
| 40 | IIIc | 9, 11, 5 | spotted$^{++}$ | C | IIIc, 9, 11, 5 | $e^{+}$, $f^{+}$ | C |
| 41 | IVa | 5 | marbled$^{+}$ | B | IVa, 5 | $a^{+}$ | B |
| 42 | IVa | 5, 4 | marbled$^{+}$, zonal$^{+}$ | B | IVa, 5, 4 | $b^{++}$ | B |
| 43 | IVa | 5, 4, 7 | marbled$^{++}$, zonal$^{+}$ | C | IVa, 5, 4, 7 | $b^{++}$, $c^{+}$ | C |
| 44 | IVa | 10, 5, 4 | local$^{++}$ | C | IVa, 10, 5, 4 | $e^{+}$ | C |
| 45 | IVa | 4, 5, 8, 23 | complete$^{+}$ | D | IVa, 4, 5, 8, 23 | $d^{+}$ | D |
| 46 | IVa | 4, 7, 8, 23 | complete$^{+}$ | E | IVa, 7, 7, 8, 23 | $d^{+}$ | E |
| 47 | IVa | 2, 6, 8, 21 | complete$^{++}$ | F | IVa, 2, 6, 8. 21 | $d^{++}$ | F |
| 48 | IVb | 10, 5, 4 | local$^{+}$ | B | IVb, 10, 5, 4 | $e^{+}$ | B |
| 49 | IVb | 11 | seepage$^{++}$ | B | IVb, 11 | $f^{++}$ | B |
| 50 | IVb | 2, 7, 5 | zonal$^{++}$ | C | IVb, 2, 7, 5 | $c^{++}$ | C |
| 51 | IVb | 5, 4 | zonal$^{+++}$ | D | IVb, 5, 4 | $c^{+++}$ | D |
| 52 | IVb | 5, 4, 6, 21 | complete$^{+}$ | D | IVb, 5, 4, 6, 21 | $d^{++}$ | E |
| 53 | IVb | 4, 7, 29, 28, 21 | complete$^{++}$ | E | IVb, 4, 7, 21, 29, 28 | $d^{++}$ | E |
| 54 | IVb | 28 | complete$^{+++}$ | F | IVb, 28 | $d^{+++}$ | F |
| 55 | IVc | 11, 5 | seepage$^{++}$ | B | IVc, 11, 5 | $f^{++}$ | B |
| 56 | Va | 5 | spotted$^{+}$ | B | Va, 5 | $a^{+}$ | B |
| 57 | Va | 10 | local$^{+}$ | B | Va, 10 | $e^{+}$ | B |
| 58 | Va | 5, 4, 1 | marbled$^{++}$ | C | Va, 5, 4, 1 | $b^{++}$ | C |
| 59 | Va | 8, 4, 5, 23, 1 | zonal$^{+}$ | C | Va, 8, 4, 5, 23, 1 | $c^{+}$ | C |
| 60 | Va | 8, 4, 23, 1 | zonal$^{++}$ | D | Va, 8, 4, 23, 1 | $c^{++}$ | D |
| 61 | Va | 8, 4, 29, 1 | complete$^{+}$ | E | Va, 8, 4, 29, 1 | $d^{+}$ | E |
| 62 | Va | 8, 28, 6, 2 | complete$^{++}$ | F | Va, 8, 28, 6, 2 | $d^{+}$ | F |
| 63 | Vb | 5 | spotted$^{+}$ | B | Va, 5 | $a^{+}$ | B |
| 64 | Vb | 9, 10 | local$^{+}$ | B | Va, 9, 10 | $a^{+}$ | B |
| 65 | Vb | 4, 17 | zonal$^{+}$ | C | Vb, 4, 17 | $c^{+}$ | C |
| 66 | Vb | 11, 5, 4 | seepage$^{+++}$ | C | Vb, 11, 5, 4 | $f^{++}$ | C |
| 67 | Vb | 5, 4, 8 | zonal$^{+++}$ | D | Vb, 5, 4, 8 | $c^{+++}$ | D |
| 68 | Vb | 8, 4, 17, 21 | complete$^{+}$ | D | Vb, 8, 4, 17, 21 | $d^{+}$ | D |
| 69 | Vb | 4, 17, 28 | complete$^{++}$ | E | Vb, 4, 17, 28 | $d^{++}$ | E |
| 70 | Vb | 28, 29, 32, 33 | complete$^{+++}$ | F | Vb, 28, 29, 32, 33 | $d^{+++}$ | F |
| 71 | Vc | 9 | local$^{+}$ | B | Vc, 9 | $c^{+}$ | B |
| 72 | Vc | 11 | seepage$^{+}$ | C | Vc, 11 | $f^{+}$ | C |
| 73 | Vc | 5, 4, 28, 21 | complete$^{++}$ | D | Vc, 5, 4, 28, 21 | $d^{++}$ | D |
| 74 | Vc | 8, 21 | complete$^{+++}$ | E | Vc, 8, 21 | $d^{+++}$ | D |
| 75 | Vc | 28, 29, 32, 33 | complete$^{+}$ | F | Vc, 28, 29, 32, 33 | $d^{+++}$ | F |

*Biul. Perygl.*, no. 18, Siuta & Motowicka-Terelak, p. 252—253.

number of observations which are being collected in the course of the cartographic soil investigations conducted to-day in detailed scales throughout the whole country.

Too large a number of observational data cannot be properly classified and their interrelations with a whole range of other parameters cannot possibly be established without the aid of computors. A simplified code should therefore be used; in the case in question, its function might be assumed by the successive numbers of the soil symbols.

*Translated by T. Dmochowska*

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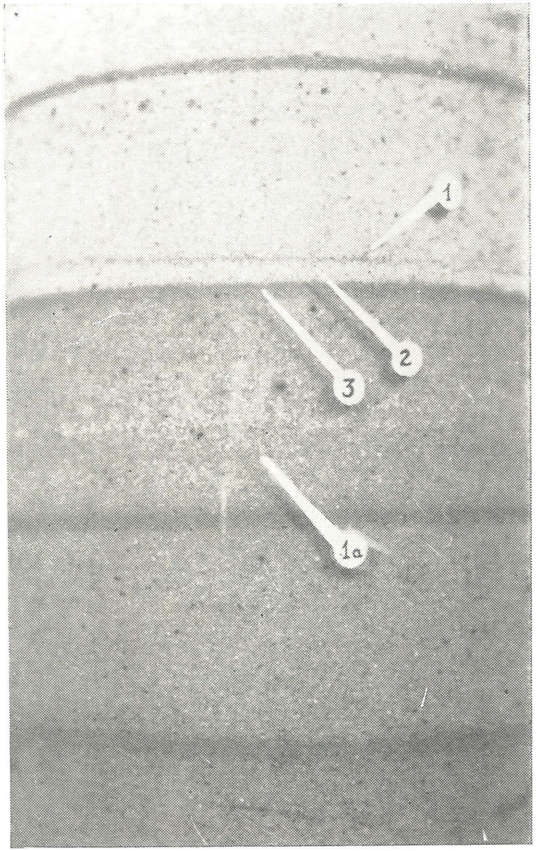


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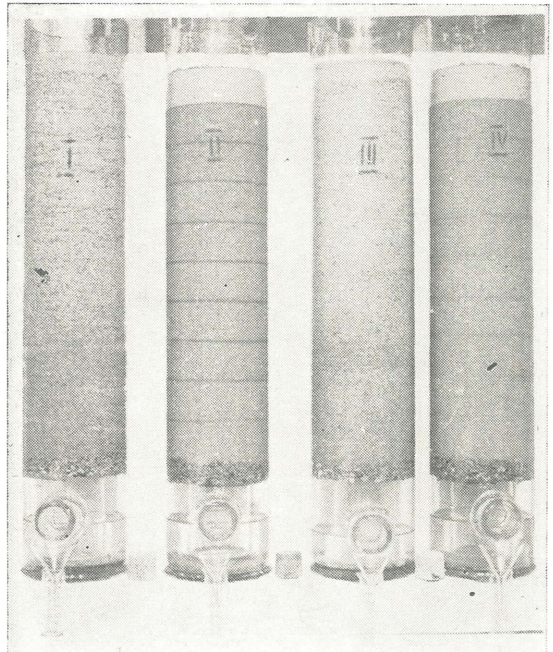



b

*Photo by M. Spóz*

Pl. 1. Laboratory experiments (see pl. 1a) on the conditions and the course of development of ferruginous small bands (1, 1a) in water-laid sand showing thin interlayers of fine-grained material (3). The small-bands of ferruginous precipitates (1) are underlain by a gley-eluvial zone, light-gray in colour. At the present stage of experiment, a second band of ferruginous precipitates is being formed. Its location is indicated by arrow 1a

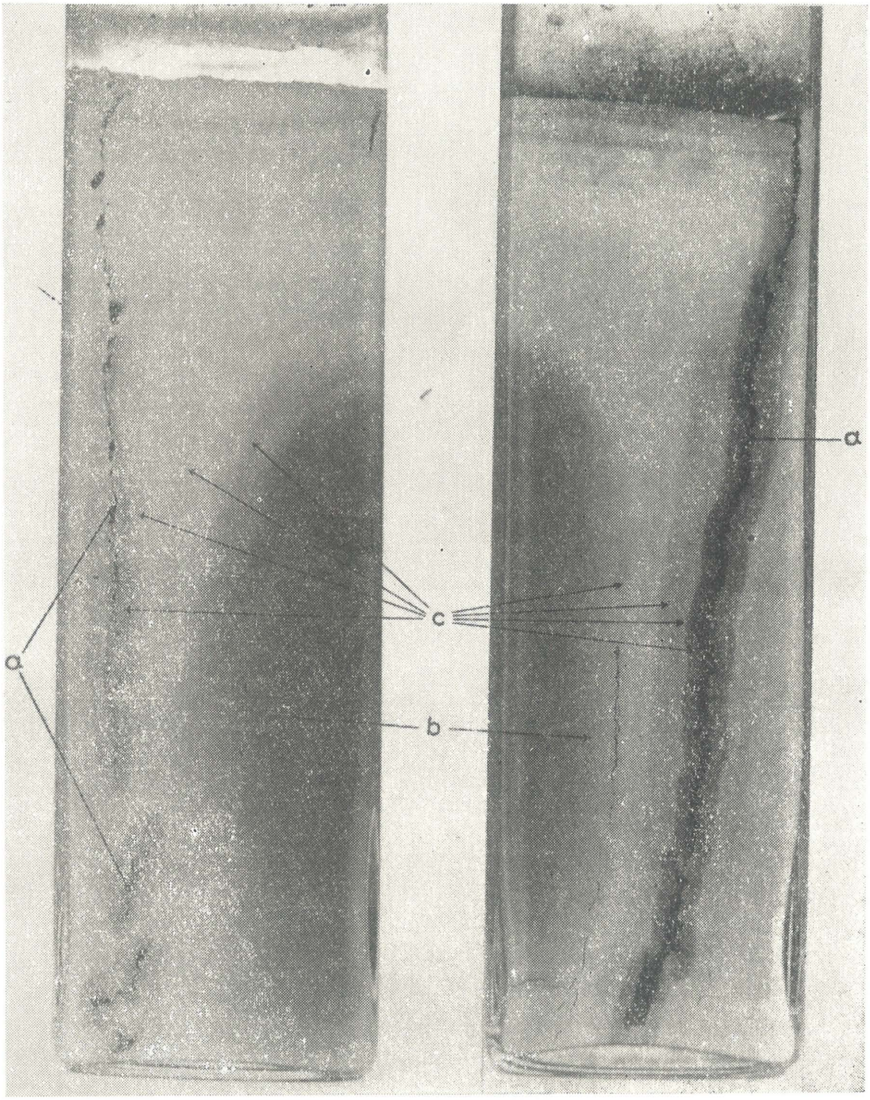
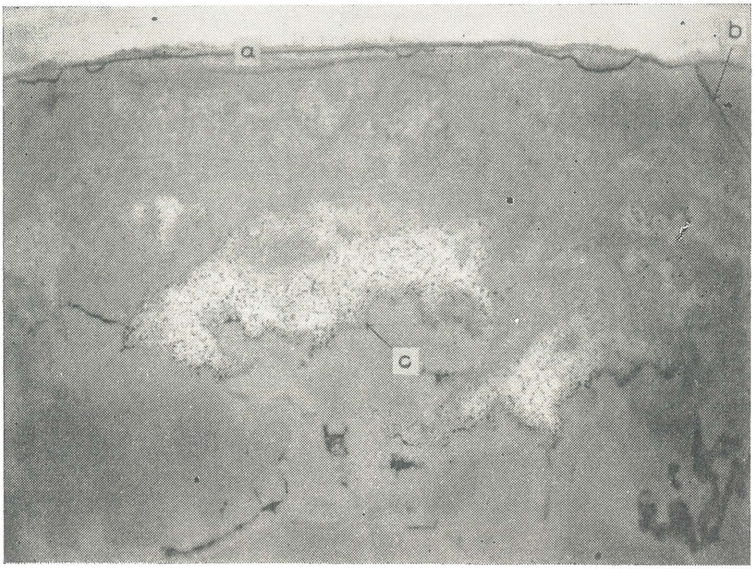



*Photo by M. Spóz*

Pl. 2. Laboratory experiments on the course of development of ferruginous precipitates dependant'y on the type of infiltration of oxygen into the reduced zone under a varying system of hydrologic conditions: (a) fissures through which oxygen penetrates, (b) strong'y reduced zone (not yet oxidized), (c) ferruginous precipitates. The fissure walls being strongly impregnated form fissure plates

*Photo by J. Siuta*

Pl. 3. Disappearance of horizontal ferruginous streaks, due to decomposition of fir-tree roots (some remains of roots are visible in the photo). The intensification of reduction processes at the site of decomposition of the organic matter, destroyed the horizontal streaks, but created at the same time conditions favouring the formation of a vertical streak running along the right-hand edge of the post-gley bleaching. Góra Puławska, loose sand at a depth of 2—3 m

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Pl. 4. Model experiment: (a) surface efflorescences, (b) crack efflorescences, (c) initial stage of the development of ferruginous borders

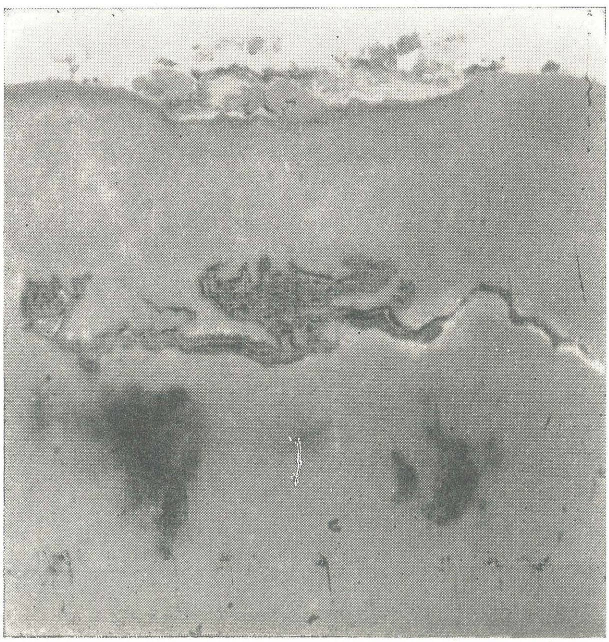

*Photo by M. Spóz*

Pl. 5. Efflorescences in voids obtained through a model experiment

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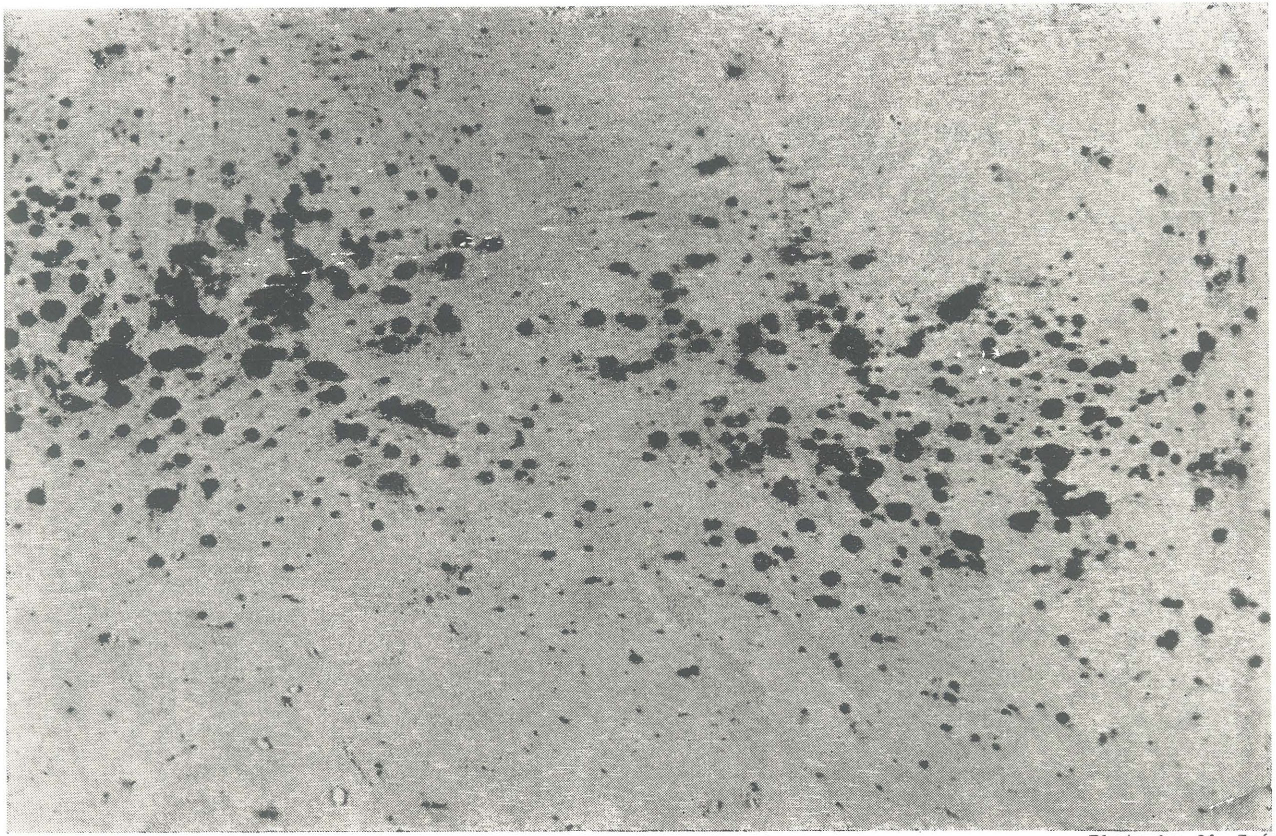
Pl. 6. Concentric spots obtained through a model experiment



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Pl. 7. Concentric black spots characteristic of silty, often strongly gleyed, loam (reduced)

*Photo by M. Spóz*

Pl. 8. Dissolution spots obtained through a model experiment

*Photo by M. Spóz*

Pl. 9. Seepage spots formed in a crack within loess material

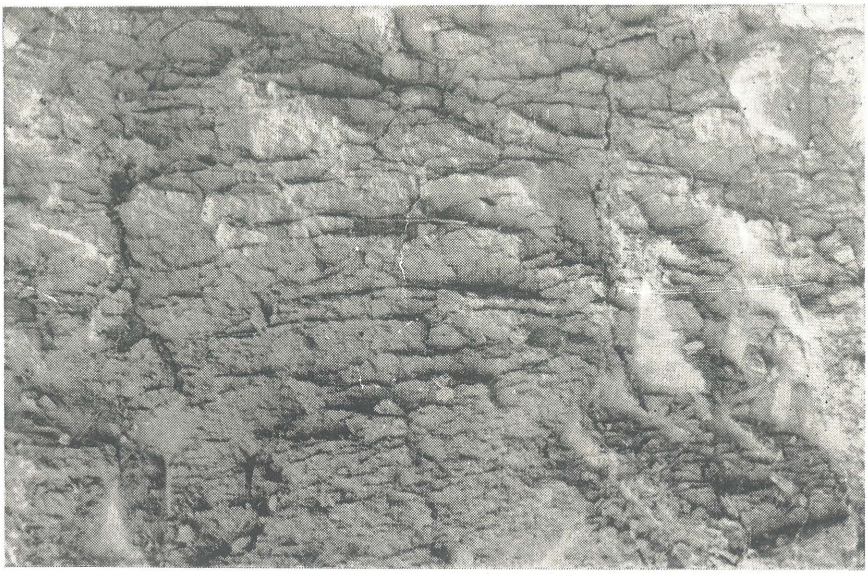


Photo by J. Siuta

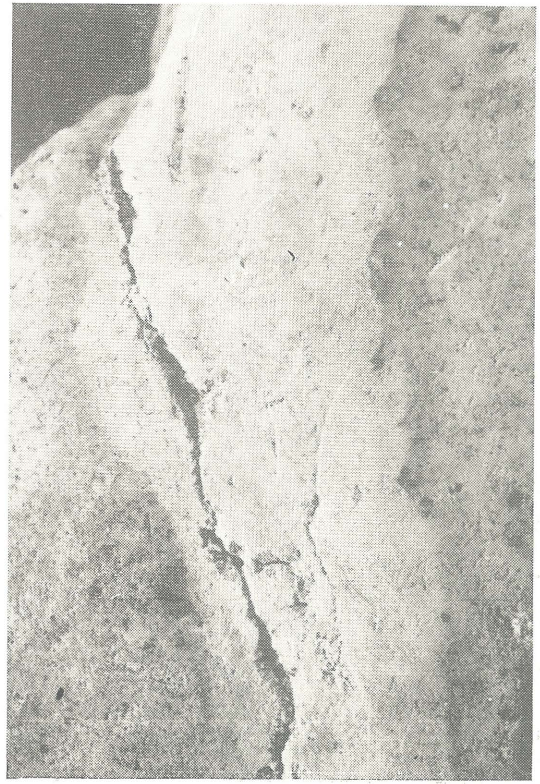
Pl. 10. Fissure-network spots in boulder clay. The boulder clay was pressed by heavy agricultural machinery. Klikawa near Puławy

Photo by M. Spóz

Pl. 11. Vertical coatings appearing in loam with loess (more than 40% of dust particles) covering the light, ash-coloured, gley-eluvial elements formed as a result of the root system

*Photo by J. Siuta*

Pl. 12. Vertical fissure streaks in the central part of a soil profile developed of loess (see fig. 3)



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Pl. 13. Vertical fissure streaks separated from the soil (pl. 12), photo taken in the laboratory

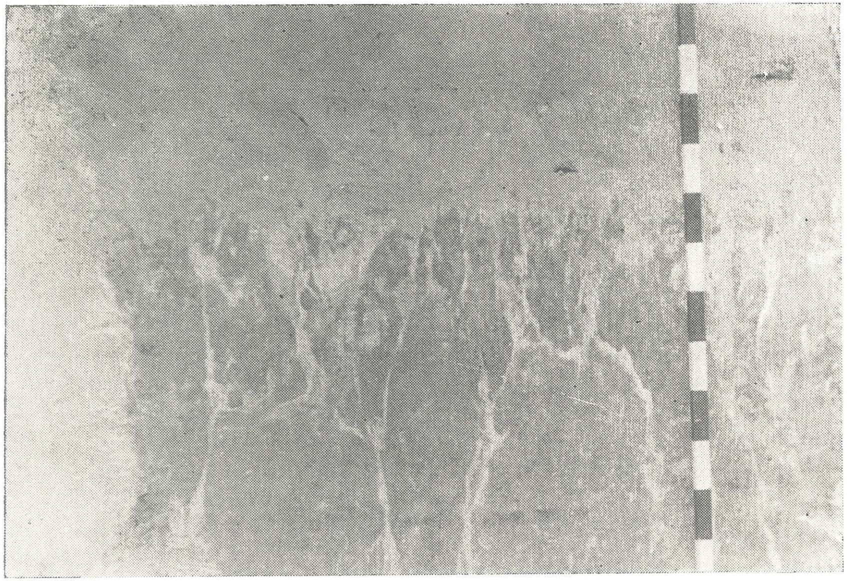

*Photo by J. Siuta*

Pl. 14. Loess soil periodically overmoist with numerous post-gley cracked light places and characteristic vertical streaks (see pl. 12)

*Photo by J. Siuta*

Pl. 15. Vertical wedge-like streaks characteristic of some sands and gravels or glaciofluvial gravels

*Photo by M. Spóz*

Pl. 16. Small bands proper in colluvial loess. The lower band is very well developed and cemented because it was formed on the border of colluvial loess and proper loess. This form is small contact plate not a small band

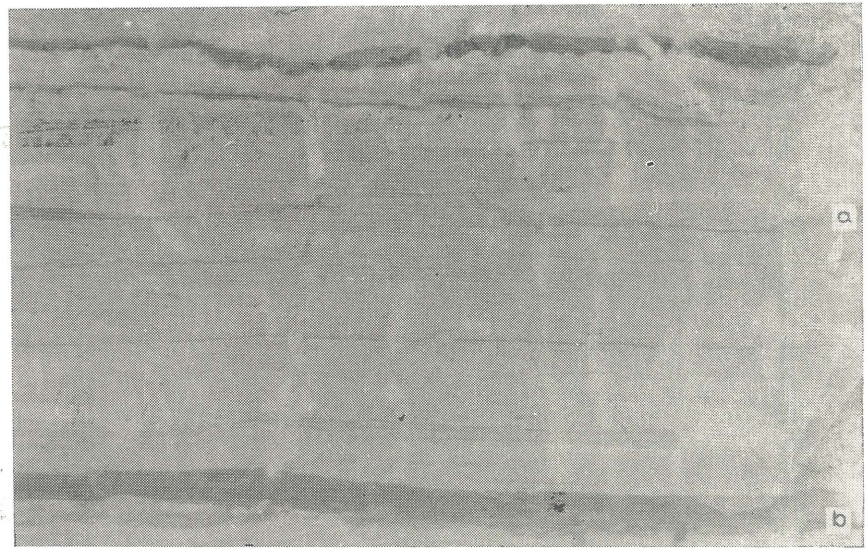


*Photo by J. Siuta*

Pl. 17. Small bands (a) and horizontal streaks (b) in loose sand. Fine example of destructive activity of dead roots on the previous formed ferruginous precipitates (vertical spots are gley-eluvial elements). Góra Puławska, loose sand

*Photo by J. Siuta*

Pl. 18. Small disturbance bands in loose sand

*Photo by J. Siuta*

Pl. 19. Small disturbance bands carved out in loose sand by wind

Photo by J. Siuta

Pl. 20. Homogeneous horizon in a sandy podzolic soil

*Photo by M. Spóz*

Pl. 21. Homogeneous horizon developed owing to the migration of iron from the lower (strongly reduced) to the upper (more oxidized) part of the loess deposit. P a n t a l o w i c e, near Przeworsk

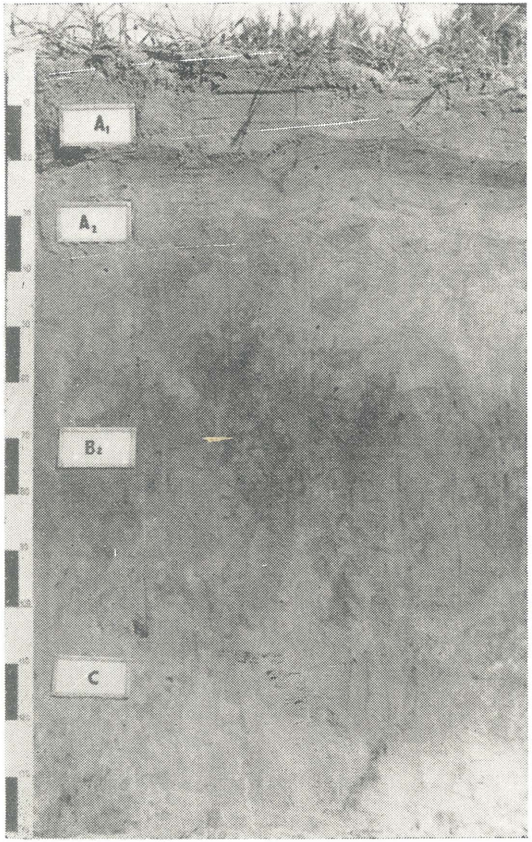


*Photo by J. Siuta*

Pl. 22. Spotted horizon in a sandy podzolic soil

*Photo by J. Siuta*

Pl. 23. Spotted horizon in a loamy pseudopodzolic soil

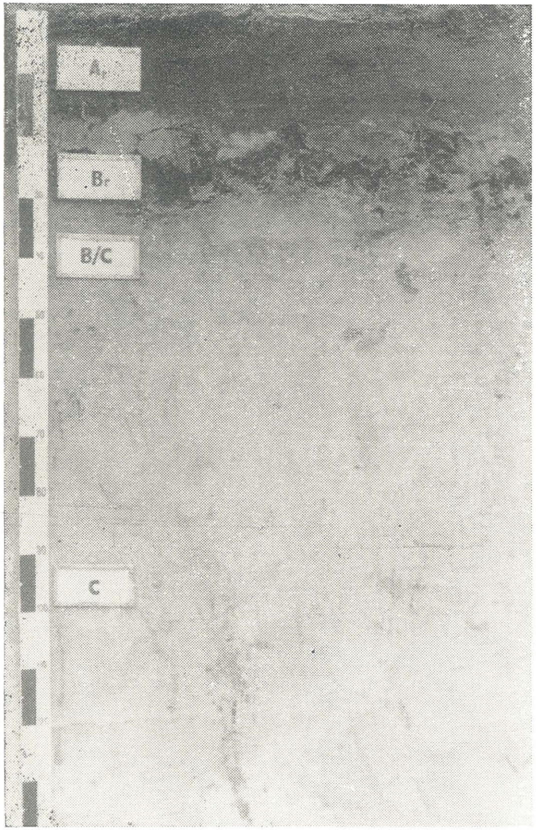


*Photo by J. Siuta*

*Photo by M. Spóz*

Pl. 25. Proper border surrounding a silty intrusion in gravel material

Pl. 24. Orstein horizon (Br) in a periodically over-moist sandy soil

*Photo by J. Siuta*

Pl. 26. Homogeneous concretions in a periodically over-moist soil

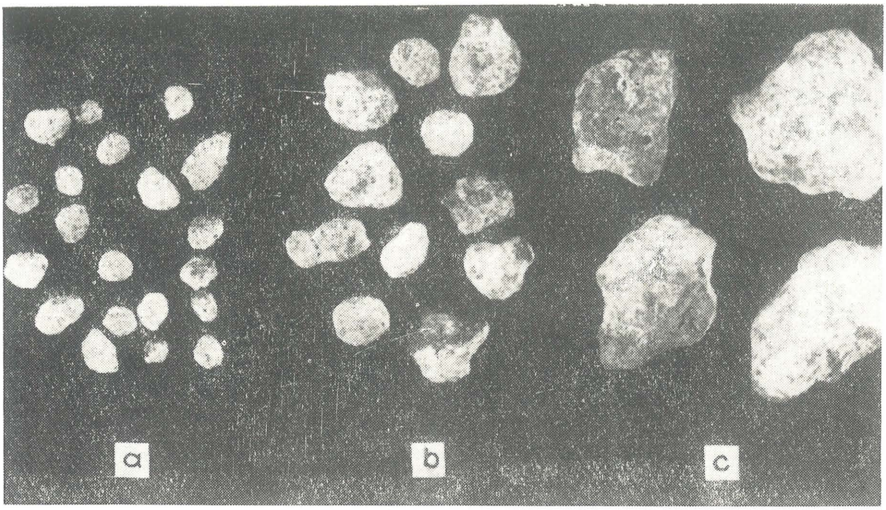


*Photo by M. Spóz*

Pl. 27. Homogeneous concretions: (a) peppers, (b) small peas, (c) small nuts (somewhat enlarged)

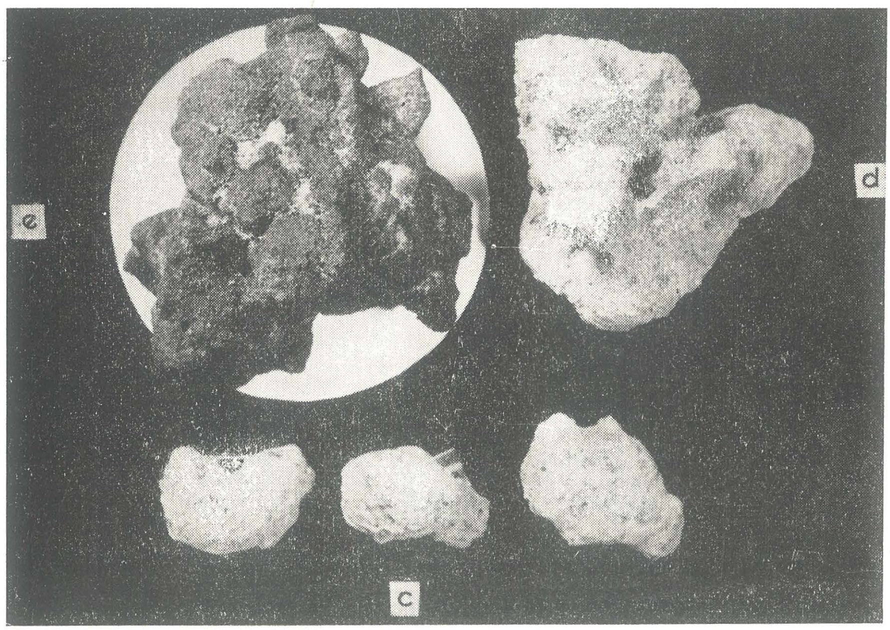


*Photo by M. Spóz*

Pl. 28. Homogeneous concretions: (c) small nuts, (d) bumps, (e) ores (somewhat reduced)

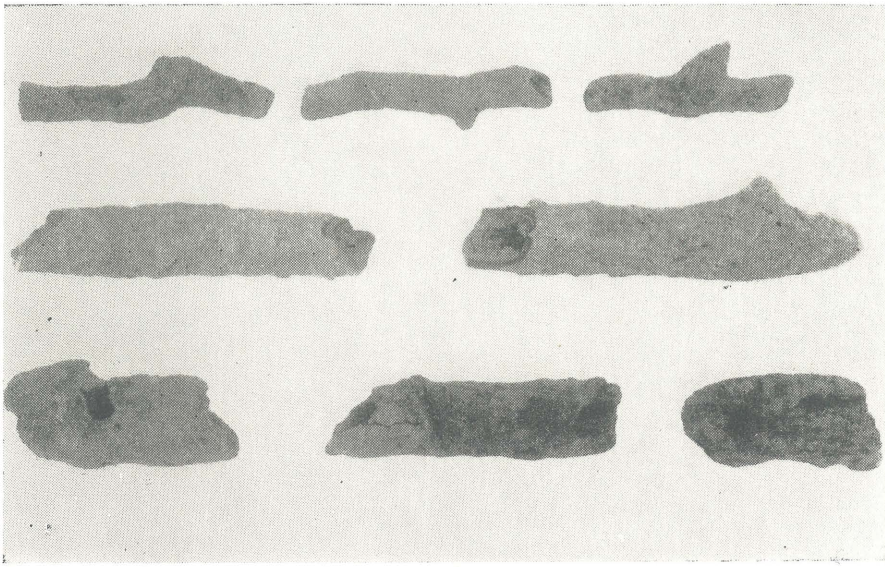

*Photo by M. Spóz*

Pl. 29. Crusty tube-like concretions, separated from alluvial loam

*Photo by M. Spóz*

Pl. 30. Crusty bubble-like concretions developed through a model experiment. The black spots covering the concretions are the orifices leading into the inside cavity of the concretions

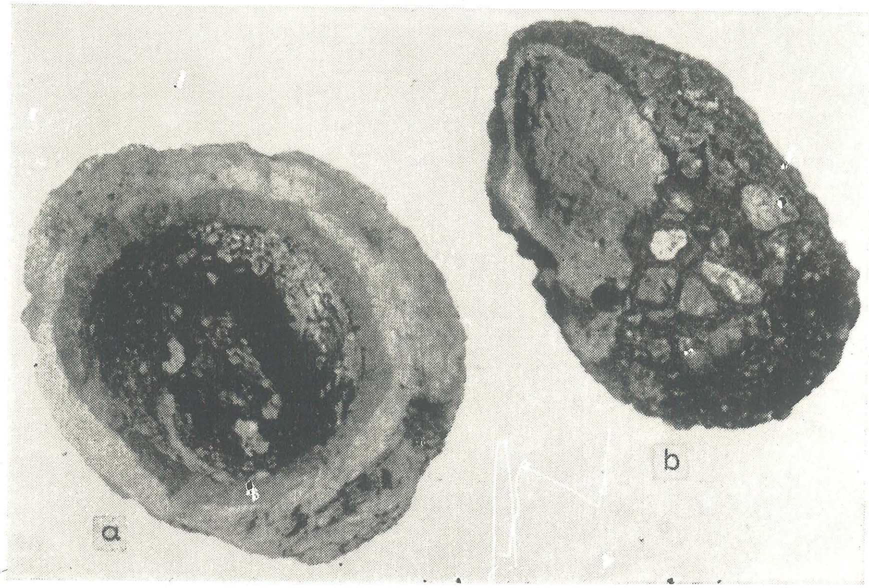


*Photo by M. Spóz*

Pl. 31. Crusty concretions: (a) ball-like, (b) pear-like, pre-Quaternary in origin

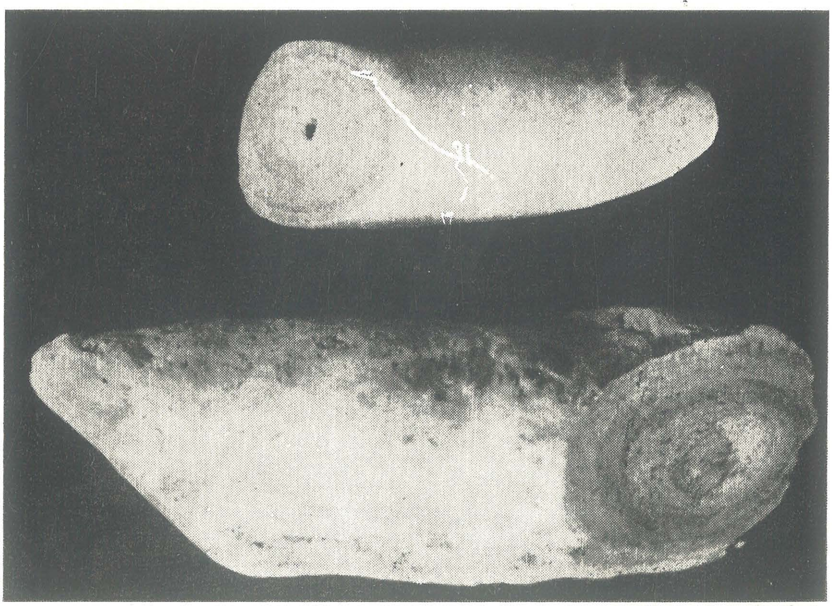

*Photo by M. Spóz*

Pl. 32. Spherically-bedded cylindrical concretions characteristic of loess unstratified deposits

*Photo by M. Spóz*

Pl. 33. Spherically-bedded cylindrical concretions with irregular structure (swells and contractions) characteristic of layered loess deposits (size twice reduced)

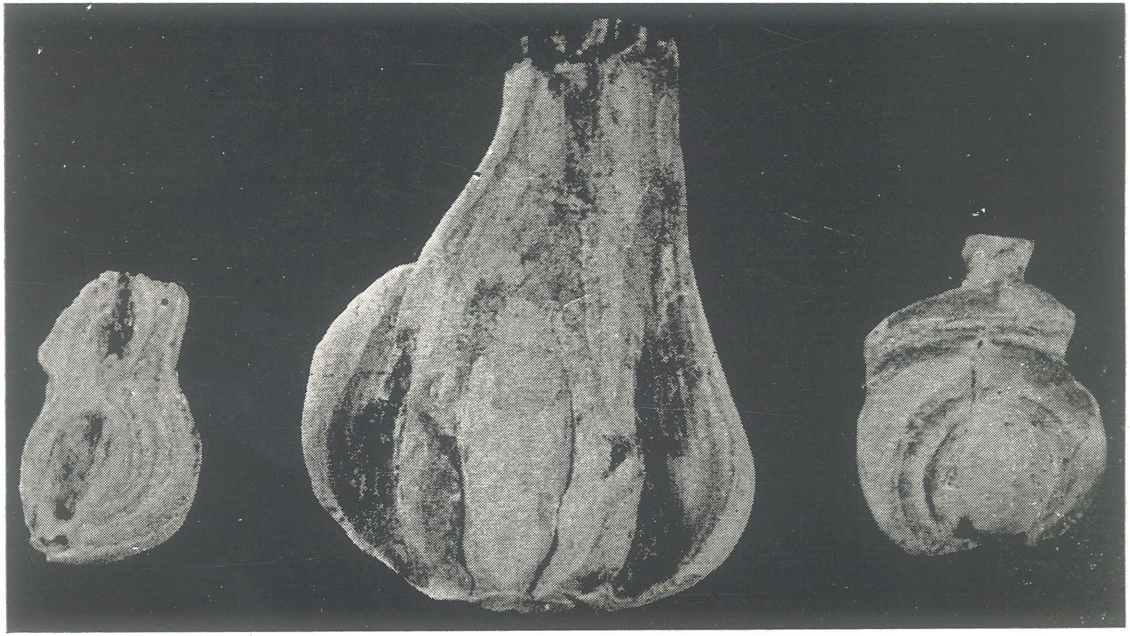

*Photo by M. Spóz*

Pl. 34. Spherically-bedded pear-like concretions separated from highly gleyed alluvial loess

Photo by M. Spóz

Pl. 35. Spherically-bedded round concretion separated from highly gleyed alluvial loess

Photo by M. Spóz

Pl. 36. Spherically-bedded concretions — ball-like chains separated from highly gleyed alluvial loess with well marked bedding. B ł a ż o w a, near Rzeszów

*Photo by M. Spóz*

Pl. 37. Spherically-bedded various concretions located at the bottom of highly gleyed loess. Błażowa, near Rzeszów

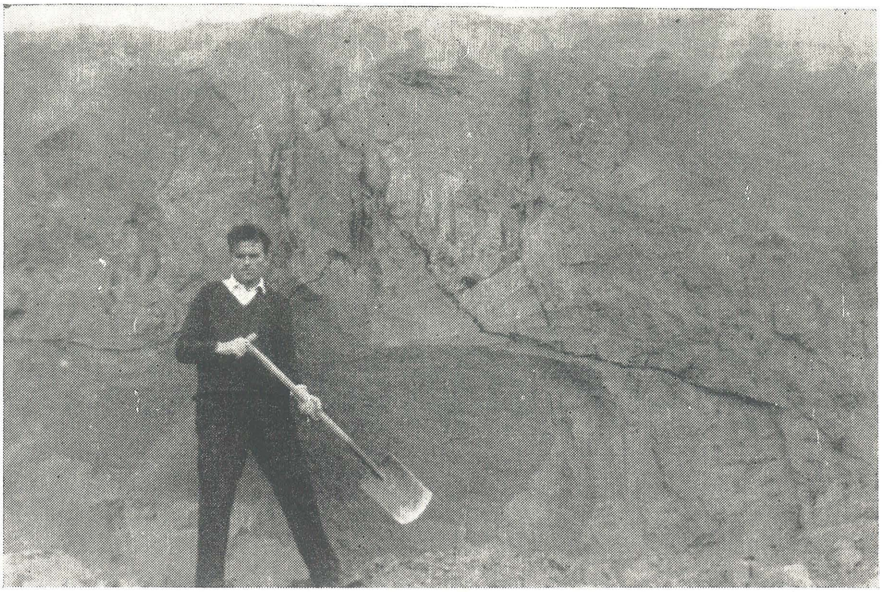

*Photo by J. Siuta*

Pl. 38. Small contact plate developed on the border of highly gleyed colluvial loess with underlying yellow loess proper. Klementowice, near Puławy

*Photo by M. Spóz*

Pl. 39. Effects of heavy rain storm on sandy soil containing contact platy-crusty concretions. Karchowice, region of Pyskowice, after a heavy rain in August, 1966