FERRUGINOUS CONCRETIONS AROUND ROOT CHANNELS IN CLAY AND FINE SAND DEPOSITS

PENTTI ALHONEN, TAPIO KOLJONEN, PERTTI LAHERMO and RAIMO UUSINOKA

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Spherically layered ferruginous concretions formed in soils in Finland are described. The cementing iron-rich material is in an amorphic state and binds the loose detrital mineral grains of quartz, feldspars, amphiboles, etc. Electron microprobe analyses show that iron and manganese are present as concentric rings around the root channels but that calcium is evenly distributed. The highest manganese content is found near the channel as a dark almost black layer or spot, but around the centre, where the content of cementing materials decreases, iron predominates. The origin of these ferruginous concretions and the significance of redox conditions in soils during their formation are discussed.

Pentti Alhonen and Raimo Uusinoka, Department of Geology and Palaeontology, University of Helsinki, SF-00170 Helsinki 17, Finland.

Tapio Koljonen, Department of Geology and Mineralogy, University of Helsinki, SF-00170 Helsinki 17, Finland.

Pertti Lahermo, Geological Survey of Finland, SF-02150 Espoo 15, Finland.

Introduction

Spherically layered ferruginous concretions formed around a plant root are described from two sites in Finland, Haapajärvi and Kemijärvi (Fig. 1). Iron-rich precipitates such as these seem to be quite common in Quaternary clay and fine sand deposits, especially in recent soils. They occur in a wide variety of soil types and the concentrations of iron and manganese are higher in the concretions than in the adjacent environment (Winters 1938; Drosdroff & Nikiforoff 1940; Sherman & Kanehiro 1954; Siuta & Gaweda 1961; Siuta & Motowicka-Terelak 1969; Bogdanov & Voropayeva 1969; Cescas, Tyner & Harmer 1970; Pawluk & Dumanski 1973; Childs 1975).

During periods of low discharge in Finland spherical concretions are found in the banks of rivers flowing through clayey and silty areas.

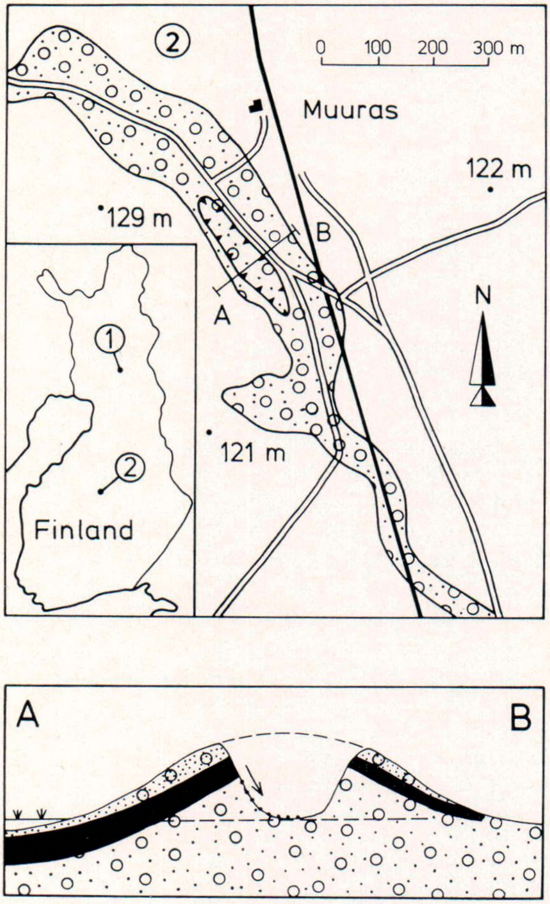

Fig. 1. The sites where the root concretions were found. 1. Kemijärvi, the bed of the river Kemijoki, silt deposits. 2. Haapajärvi, the clayey layer (black in section A—B) in the wall of a gravel pit in an esker at Muuras (see map 2). Abundant concretions have been rolled down to the bottom of the pit by the action of rill-wash erosion (see arrow and spots).

The material that falls from the banks is sorted by water and the concretions remain after the finer material has been carried away. In the walls of sand pits, smaller and more brittle concretions are seen down to a depth of 1 to 1.5 m from the surface. The present study of the chemistry and mineralogy of soil concretions is an attempt to compensate for the little attention that has been paid to the origin and structure of concretions of this type in Finland (the only exception is the work by Frosterus 1913).

Description of the concretions

The form and size (0.5 to 3.0 cm in diameter) of the concretions studied varies, but in principle they include groups identical with those described by Siuta & Motowicka-Terelak (1969, p. 242) from Poland. These ferruginous concretions can be divided into five varieties at least, *viz*. cylindrical, finger-like, pear-like, round and ball-like chains. The bulk of them in Finland are roundish or longish with layering visible as a relict from the original vertical cut of the sediment (usually silt or fine sand) in which they were formed (Figs. 2 and 3).

X-ray and chemical analyses

X-ray analyses were made from different layers of the concretion. Only quartz, plagioclase and potash feldspar were identified with certainty, quartz being the main component followed by plagioclase. It is, however, likely that very small quantities of mica and amphibole are also present. No iron minerals were found. The iron and manganese present are in a subamorphic state (*cf.* Koljonen, Lahermo & Carlson 1976).

From one concretion from Haapajärvi and Kemijärvi the major elements were analysed by the conventional wet method, the alkalis by atomic absorption spectrometry, and the phosphorus colorimetrically. The chemical composition (see Table 1) is similar to that found in lake ores and in the B-horizon of the podzol. Iron, manganese, phosphorus and titanium are enriched. Although iron and manganese are mixed with each other, the latter commonly tends to migrate to the more oxidizing milieu (Hem 1964). Phosphorus is probably collected by iron phosphate and titanium as hydroxide precipitate, both of which dissolve with difficulty.

Because iron, manganese and calcium may form cementing material in sediments, their distribution in the different layers of the concretions (Figs. 4 and 5) was examined with a

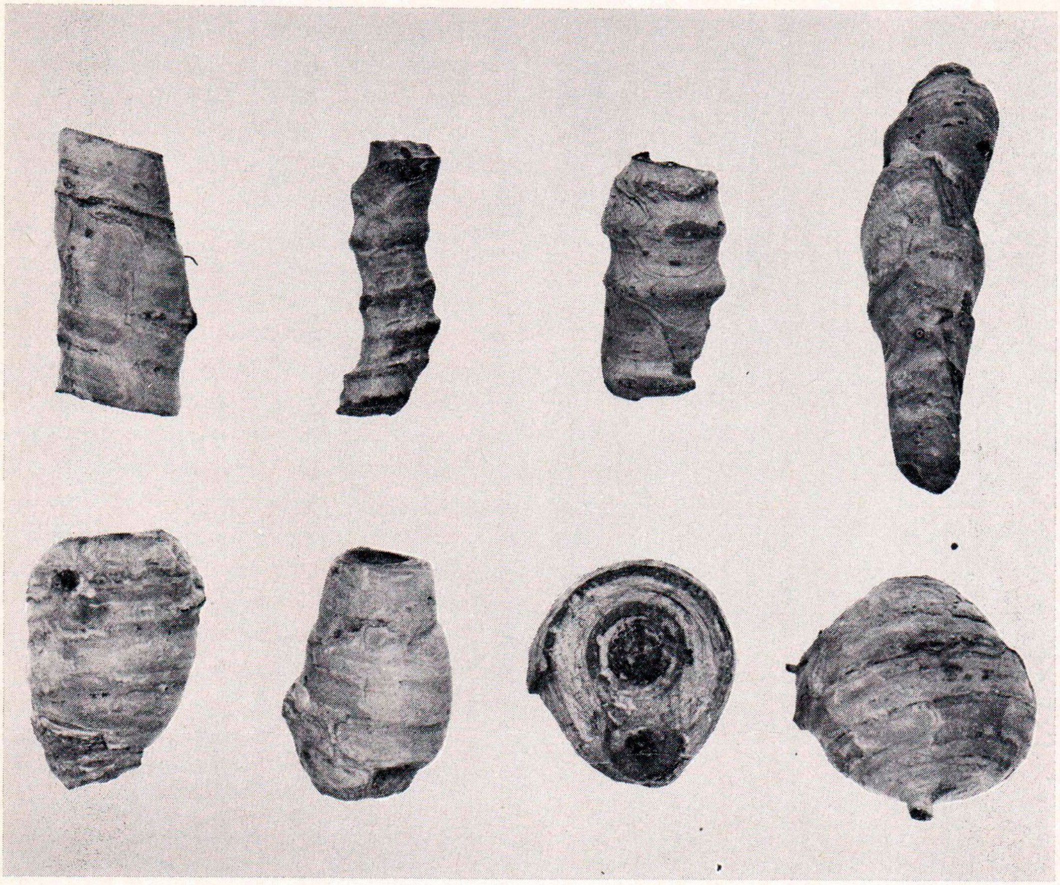

Fig. 2. Typical root concretions in the clayey layer of the deposit at Haapajärvi. In the top there are oblong (spindle-like), somewhat irregular concretions. The ones in the middle of the row exhibit ring-like knobs with subregular spacing caused by varves. In the bottom row roundish concretions are visible, the first one on the right showing the pipe-like head of the root channel. In the split concretion two root channels can be discerned (*cf.* Fig. 5).

TABLE 1.

Wet chemical analyses of the concretions from Kemijärvi (No. 1) and Haapajärvi (No. 2). Anal. C. Ahlsved.

	No. 1	No. 2
SiO_2	43.46	50.93
TiO_2	0.79	1.10
Al_2O_3	11.97	10.98
FeO	1.22	0.44
Fe_2O_3	21.93	17.16
MnO	0.11	0.56
MgO	3.20	2.10
CaO	2.28	1.28
Na_2O	1.72	2.58
K_2O	1.55	2.28
P_2O_5	1.00	0.23

Cambridge Geoscan Electron Probe micro-analyser at the Geological Survey of Finland. The determinations were made by Miss T. Paasivirta. The results indicate that iron and manganese were present in concentrical rings and enriched towards the centre, but that calcium was evenly distributed (1.5 to 3.0 percent) and is not a major constituent in the cement. In the horizontal cut, the manganese content is highest (over 10 percent) in a dark layer or spot near the root channel where 10 to 15 percent iron was found. The chemical composition, however, fluctuates and only in some concretions was manganese ap-

Fig. 3. Typical brittle tube-like concretions with irregular shapes in fine sand, Mouhijärvi, southwestern Finland.

preciably enriched. In the outermost parts iron and manganese were evenly distributed. In the brownish rings around the centre, the iron seems to predominate over manganese. Some semiquantitative determinations gave 14 to 19 percent iron and 0.1 percent manganese in the outer rings.

Discussion

The structure of these concretions clearly indicates that the cementing material was deposited around a plant root or in a root channel. They were formed in homogeneous fine-grained soil such as clay and silt or sometimes fine sand. The concentric layering of the concretions suggests seasonal (periodic) growth, since the enrichment of iron and manganese greatly depends on the redox conditions in the soils (Sherman & Kanehiro 1954; Bogdanov & Voropayeva 1969, see also Cescas, Tyner & Harmer 1970, p. 642). During dry periods air invades the ground along the root channel filled with material rich in humus and more porous than the surrounding soil. Thus oxygen is adsorbed into the walls in sedimentary material around the channel. In wet periods water invades the root channels, and oxygen consumption increases because of the decomposition of the humus. The iron content of the water in these oxygen-poor reducing conditions may be substantial. The ferruginous water also invades the sedimentary deposits around the channel by pushing the air ahead of it, whereupon the iron is oxidized. The depth to which the water and air invade is variable. As stated before, the outcome of these events is the formation of concentric rings of precipitate. Under certain conditions, also the layers formed earlier may dissolve and new ones form in different parts of the concretion. Sometimes even irregular forms occur (see Fig. 6).

In coarser material no concentric concretions can form, because the material is more permeable to air and water. In coarse silt and more particularly in fine sand, tube-like crusty concretions are formed (Fig. 3), whose structure is not generally as marked as is that of the concentric concretions.

Easily breakable tubes are formed in sand, and oblong and more roundish forms of concretion in fine-grained material only, *e.g.* in clay and silt. The ring structure seems to form in soil. It is tentatively proposed that this structure corresponds to that of the Liesegang rings, which have been observed to form in colloids, *e.g.* in opal and iron concretions in sandstone.

Frosterus (1913), who describes ferruginous concretions in podzolized grey clay (B horizon) from Paimio and in varved clay from Leppäkoski (southern Finland), has stated that the formation of coloured zones around plant roots, a phenomenon visible in clay down to the upper limit of

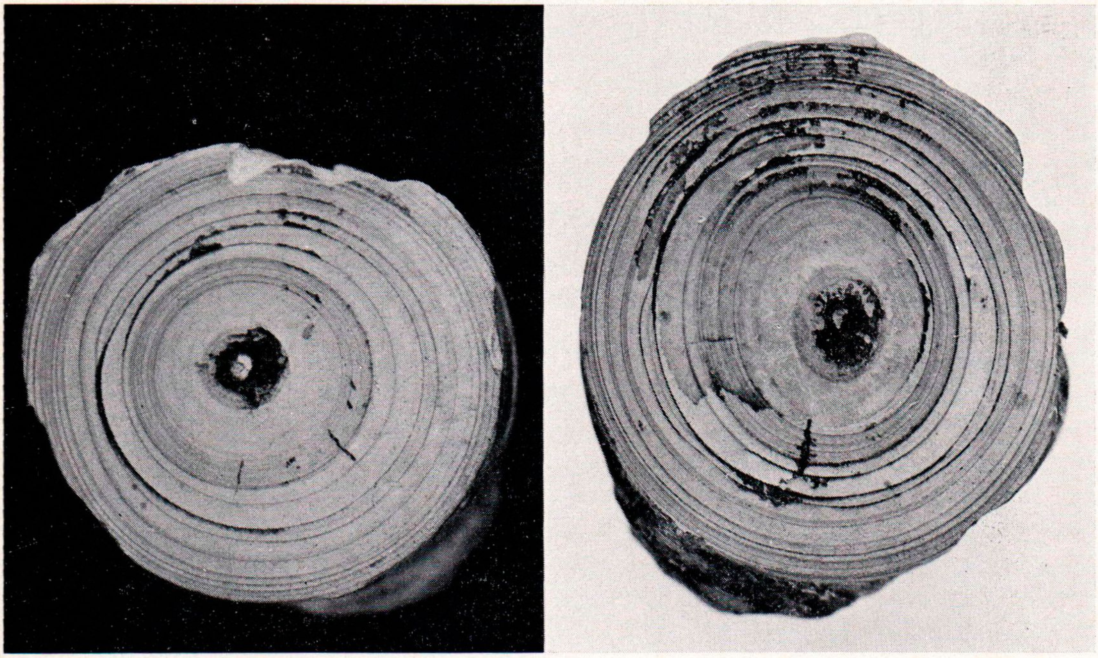

Fig. 4. Concentric ring-like structure in the concretions from Haapajärvi. The contents of iron and manganese are highest around the root channel. The pictures are of the same concretion from different depths. Magn. *c.* 3 ×. Photo E. Halme.

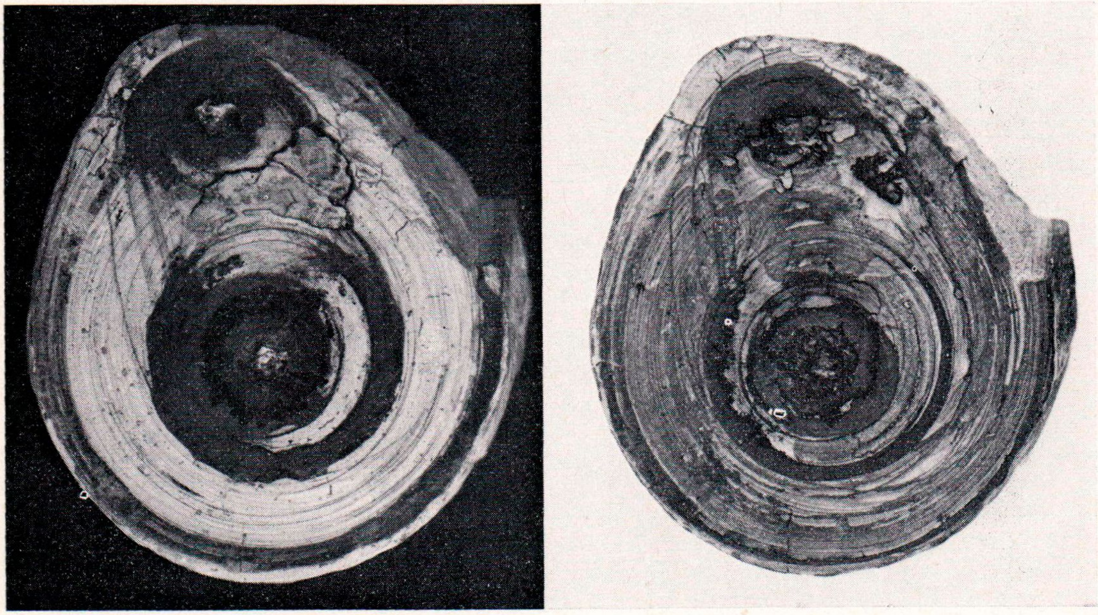

Fig. 5. Concentric ring-like structure and two root channels in a concretion from Haapajärvi. The other channel at the side may be of later origin, no clear ring-like structure having developed around it. The channel at the side, however, had caused the nonsymmetric growth of the concretion. The dark area immediately around the root channel indicates the site of the highest concentration of manganese. The pictures are of the same concretion from different depths. Magn. *c.* 3 ×. Photo E. Halme.

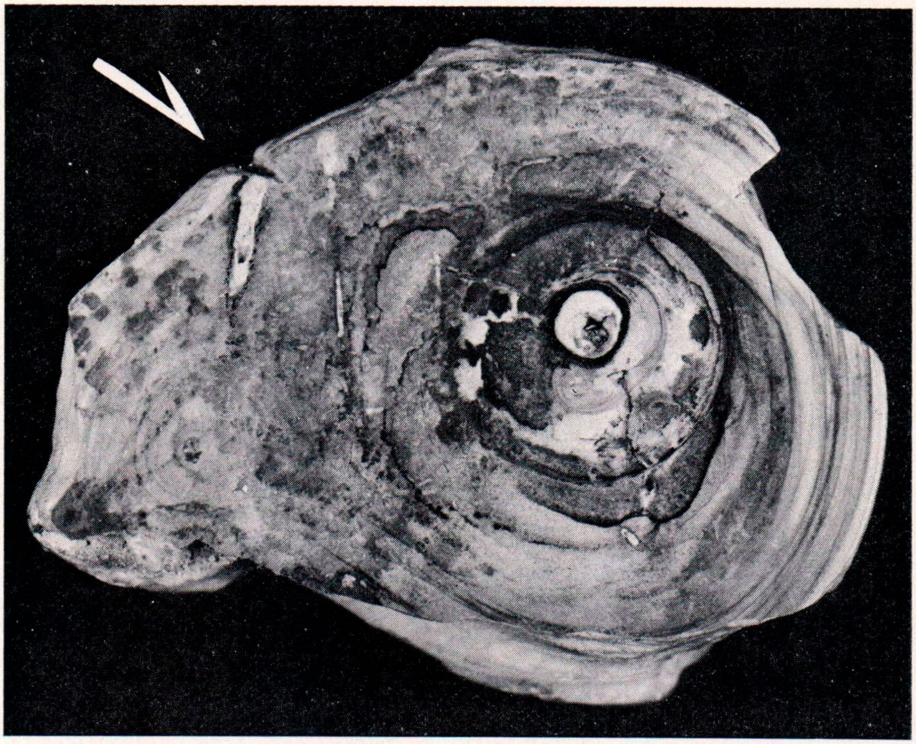

Fig. 6. An irregular concretion from Haapajärvi. The highest iron and manganese contents are concentrated in the centre part are heavily weathered. The arrow indicates small transversal, highly leached root channel. In the left part of the concretion there are some faint rings around tiny channel. Magn. *c.* 5 x. Photo E. Halme.

the ground water, could have some bearing on the origin of the rusty-coloured horizontal layers.

The iron-manganese concretions can also start to form around a living root or around an aggregate containing organic material. If oxidating and reducing conditions switch over successively many times, the accumulation is enriched in oxides of iron and manganese and is transformed into a concretion (Bogdanov & Voropayeva 1969, p. 654). The concentration of iron- and manganese-bearing precipitates around mineral particles can also start the formation of the concretions (Childs 1975). The precipitation can take place, at least partially, as the result of bacterial activity (*Leptothrix*, *Gallionella*), which in a way initiates the formation of concretions.

Furthermore, the organic material of the soil markedly promotes the reducing reactions and hence also the formation of concretions (*cf.* Siuta & Motowicka-Terelak 1969; McKenzie 1971). Water-saturated soil rich in organic material can show a variation in redox conditions, which makes the formation of the concretions possible. Although the deposit of concretions at Haapajärvi is relatively high up on the slope of an esker, even here the clayey layer is temporarily saturated by water owing to the fine grain size of the material. At Kemijärvi concretions have been found by the river Kemijoki, where the flood water is seasonally fringed by silty layers.

Only rough estimates can be presented of the origin of the iron and manganese of these concretions. The hydrogen ionic atmosphere that possibly formed around the plant roots (*cf. e.g.* Keller & Frederickson 1952) as a weathering promoting factor may be of some value in establishing the origin. However, it is evident that the water, which has consumed its oxygen in the decomposition of organic matter, is able, while slowly sinking in a compact soil, to dissolve enough iron and manganese from the small mineral particles of the soil.

As stated before, the formation of ferruginous concretions is usually associated with the process of soil podzolization, in which alterations in oxidizing and reducing conditions are a prerequisite for the development of concretions (Bogdanov & Voropayeva 1969). Cescas, Tyner and Harmer (1970, p. 642) state that the distribution of iron and manganese is caused by the variation in the redox potential during the formation of the concretions, assuming that the »varved» structure indicates the annual growth in the origin of the concretions. This is not necessarily true. The main factor is the alteration in physico-chemical conditions in the soil-forming process due to oxidizing and reducing, *i.e.* dry and wet, periods. Cescas, Tyner and Harmer *(op. cit.)* state, however, that postglacial climatic fluctuations may have indirectly provided the major control of Eh flux involved in the formation of concentrically layered concretions. The date of their formation, however, is unknown. It is possible that concretions can be employed as palaeohydrological indicators.

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