FISHERIES AND MARINE SERVICE

Translation Series No. 3694

Lake and bog ores of south and central Sweden: formation, occurrence and practical importance - Summary

by E. Naumann

Original title: Södra och mellersta Sveriges sjöoch myrmalmer; deras bildningshistoria, utbredning och praktiska betydelse (Uber die See- und Sumpferze Süd- und Mittelschwedens. Ihre Genesis, Vorkommen und praktische Bedeutung. Resümee)

From: Sver. Geol. Unders., Ser. C: (297): 178-194, 1922

Translated by the Translation Bureau(AK)
Multilingual Services Division
Department of the Secretary of State of Canada

Department of the Environment
Fisheries and Marine Service

Freshwater Institute
Winnipeg, Manitoba

1976

26 pages typescript

DEPARTMENT OF THE SECRETARY OF STATE
TRANSLATION BUREAU

MULTILINGUAL SERVICES DIVISION

CANADA

SECRÉTARIAT D'ÉTAT
BUREAU DES TRADUCTIONS

DIVISION DES SERVICES MULTILINGUES

F&M # 3694

TRANSLATED FROM — TRADUCTION DE: German

INTO — EN: English

AUTHOR — AUTEUR: Einar Naumann

TITLE IN ENGLISH — TITRE ANGLAIS

Lake and Bog Ores of South and Central Sweden:
Formation, Occurrence and Practical Importance - Summary

TITLE IN FOREIGN LANGUAGE (TRANSLITERATE FOREIGN CHARACTERS)
TITRE EN LANGUE ÉTRANGÈRE (TRANSCRIRE EN CARACTÈRES ROMAINS)

Orig.Swed.title: Södra och mellersta Sveriges sjöoch myrmalmer;deras bildningshistoria, utbredning och praktiska betydelse.
(Über die See- und Sumpferze Süd- und Mittelschwedens. Ihre Genesis,Vorkommen und praktische Bedeutung. Resümee.)

REFERENCE IN FOREIGN LANGUAGE (NAME OF BOOK OR PUBLICATION) IN FULL. TRANSLITERATE FOREIGN CHARACTERS.
RÉFÉRENCE EN LANGUE ÉTRANGÈRE (NOM DU LIVRE OU PUBLICATION), AU COMPLET, TRANSCRIRE EN CARACTÈRES ROMAINS.

Sveriges Geologiska Undersökning, Avhandlingar och Uppsatser, Ser. C.

REFERENCE IN ENGLISH — RÉFÉRENCE EN ANGLAIS

Geològical Investigation in Sweden, Treatises and Articles, Ser. C.

PUBLISHER — ÉDITEUR	DATE OF PUBLICATION / DATE DE PUBLICATION			PAGE NUMBERS IN ORIGINAL / NUMÉROS DES PAGES DANS L'ORIGINAL
not shown	YEAR / ANNÉE	VOLUME	ISSUE NO. / NUMÉRO	178 - 194
PLACE OF PUBLICATION / LIEU DE PUBLICATION: not shown	1922		297	NUMBER OF TYPED PAGES / NOMBRE DE PAGES DACTYLOGRAPHIÉES: 26

REQUESTING DEPARTMENT / MINISTÈRE-CLIENT: Environment

TRANSLATION BUREAU NO. / NOTRE DOSSIER NO: 1101088

BRANCH OR DIVISION / DIRECTION OU DIVISION: Fisheries & Marine Office of the Editor

TRANSLATOR (INITIALS) / TRADUCTEUR (INITIALES): A.K.

PERSON REQUESTING / DEMANDÉ PAR: Allan T. Reid, Scientific Documentation

YOUR NUMBER / VOTRE DOSSIER NO: 1101088

DATE OF REQUEST / DATE DE LA DEMANDE: 30 January, 1976

UNEDITED TRANSLATION
For information only
TRADUCTION NON REVISÉE
Information seulement

APR - 7 1976

SOS-200-10-6 (REV. 2/68)
7530-21-029-5333

DEPARTMENT OF THE SECRETARY OF STATE
TRANSLATION BUREAU

MULTILINGUAL SERVICES DIVISION

CANADA

SECRÉTARIAT D'ÉTAT
BUREAU DES TRADUCTIONS

DIVISION DES SERVICES MULTILINGUES

CLIENT'S NO. Nº DU CLIENT	DEPARTMENT MINISTÈRE	DIVISION/BRANCH DIVISION/DIRECTION	CITY VILLE
	Environment	Fisheries & Marine Office of the Editor	Ottawa
BUREAU NO. Nº DU BUREAU	**LANGUAGE LANGUE**	**TRANSLATOR (INITIALS) TRADUCTEUR (INITIALES)**	
1101088	German	A.K.	APR - 7 1976

In: Sveriges Geologiska Undersökning, Avhandlingar och Uppsatser, Ser.C. No. 297, pp. 178-194, 1922

Lake and Bog Ores of South and Central Sweden: Formation, Occurrence and Practical Importance

Summary

by Einar Naumann

Introduction

The various questions regarding the old problem of the genesis of lake and bog ores have, so far, never been the object of a summarizing paper from a present-day research aspect. Moreover, several special questions still remain quite unclear. The present paper therefore intends to closely examine a number of special questions and to provide a summarizing presentation of the whole problem. However, it is obvious that, in several respects, this paper cannot provide a final answer to all these special questions which belong to the most diverse fields of the natural sciences. Nevertheless, it will clearly delineate the problem for future research.

I. The Lake and Bog Ore Question in General

I. Definition of the Terms Lake and Bog Ores

The definition will be based strictly on genetic factors, and the present location of the ores will therefore not be taken into consideration. Hence, lake ores are formed in lakes, bog or meadow ores, however, in or on wet ground.

II. Survey of Existing Literature

The first summarizing presentation about the origin of the ores was provided already in 1865 by STAPFF. Subsequently, more specific questions regarding the biology of the ores were dealt with mainly by WINOGRADSKY, MOLISCH and HARDER and the chemistry of the ores was treated by ASCHAN, AARNIO and ODÉN. To be mentioned is also the geologically very significant research work by VOGT. Other papers are of less importance.
They are listed in the bibliography which, however, contains only publi- (179)
cations that are directly related to the ore question. Not listed either are a number of lesser, specialized publications, the titles of which may be found in the papers by the authors mentioned.

III. Principle of Ore Formation

1. Chemical Aspect

Ore formation is dependent on separation of iron from the ground water. The original material therefore belongs to the environment where it is leached out by various processes, mainly from the iron-rich moraine material. This solution is transported, and sooner or later reprecipitated - in lakes (lake ore), or in or on moist ground (bog ore). We therefore distinguish:

1. Dissolution of the iron: It probably takes place mainly by the effect of humic acids. However, organisms may also take part in this process by bacterial activity. Cp. SÖHNGEN, 1914.

2. Transport of the iron: According to ODÉN, it probably takes place mainly in the form of iron humates in true or colloidal solution. According to ODÉN, other combinations (such as, for example, $Fe(HCO_3)_2$) may be relatively seldom. - AARNIO explains transportation mainly in the form

of a solution of colloidal Fe_2O_3 caused by humus as a protective colloid. - However, one probably cannot say as yet with certainty whether there actually exists such a possibility.

3. Precipitation of the iron: According to ODÉN, oxidation of the humic acids is mainly involved. In this process, the iron is released in ionic form and as a result the less oxidized humic acids coagulate. The result is a fine-grained precipitate. - The same effect is obtained if the $Fe(CO)_3)_2$ is simply precipitated by oxidation as $Fe(OH_3)$. - According to AARNIO, the precipitation of the Fe_2O_3 iron in the form of a fine-grained precipitate is caused simply by the dilution of the transport solution. - Regarding the processes taking place during dissolution, transportation and precipitation of the manganese, nothing is known in detail as yet. Regarding further details on the chemistry of the ores, see above all the papers by O. ASCHAN, AARNIO and ODÉN.

2. Biological Aspect

As may be seen from the above discussion, the precipitation of the iron may be explained on a purely chemical basis. However, one may ask whether organisms are not actually more or less involved. Based on these viewpoints, the following possibilities might be expected:

I. Effect of higher or lower plants on the environment:

A. Effect on the Water

Production of O_2 or alkalies by the higher flora. - Cp. MOLISCH, 1892, 1910. - In addition, various metabolic products of morphologically undetectable bacteria. - Cp. SÖHNGEN, HARDER.

This changes, of course, the environment by promoting iron precipitation.

B. Effect on the Ground

The soil material is loosened and transformed into a lumpy or rootlet-tube structure. In this process,the animal world also takes a lively part, particularly on lake bottoms. - Cp. E. NAUMANN, 1919.

The processes mentioned under (A) promote precipitation, those mentioned under (B), however, provide a favourable initial material for enrichment.

II. The microscopic flora as a specific factor precipitating iron:

This includes the whole morphologically detectable siderophile formation. For more details, see also MOLISCH, 1910; HARDER, 1919; NAUMANN, 1922(a).

3. The Shaping Problem

Both lake and bog ores occur in a great many shapes. However, the factors determining these shapes are still completely unknown.

II. Origin and Occurrence of Lake Ores

I. Investigational Area

With a view to investigating the formation of the lake ores in relation to the above mentioned factors, three different areas were chosen in the lake-rich province of Småland: The surroundings of Aneboda and Lamhult, of Åminne, and of Huseby. All these areas exhibit typical formations of lime-deficient primitive rocks. Dominant are granites and gneisses, with a rather unimportant amount of interspersed diorite. The landscape is characterized mainly by moraine deposits. It is covered for the most part with coniferous forests, occasionally, however, with often quite extensive high-moor formations. Humus waters therefore are very characteristic. - About 40 small and large lakes were investigated here.

II. Investigational Technique

Work in the fieldpermits in the first place the establishment of a reliable concept concerning the location of the lake ores in the limnetic zonation, that is, acquisition of an accurate knowledge of the stratification conditions of the ore deposits.

Work on the lake therefore was always started with sounding lines from the shore. The NAUMANN lead line was used; see Fig. 1. After the discovery of the ore deposits - they generally lie parallel to the shoreline - there follows accurate sounding with NAUMANN's profile line; see Fig. 2. To obtain abundant material, of course, a dredge was also used, both inside and outside of the ore deposits. In certain cases, quantitative ore-production investigations were carried out with LARSSON's apparatus; see Figs. 3, 7. It consists of a tube provided at the top with a cover valve, which is rammed into the ground.

The samples were sieved and elutriated at the site. During treat- (181)
ment of the samples in the laboratory, the attention was directed primarily to the possible occurrence of morphologically detectable siderophile organisms, that is, to the effect animals and plants might have on the structure of the ground.

For further details regarding the method of these investigations see E. NAUMANN, 1917(a).

III. Principle of Lake-Ore Formation

The principle of the lake-ore formation may be summarized briefly as follows: The precipitation of the iron compounds brought in with the ground water produces a fine-grained material which then is concentrated, relatively simultaneously or subsequently, on certain initials. The precipitation of the fine-grained material is not directly dependent on the morphologically detectable plant world. Iron-encrusted plants are absent in the ore deposits, and the morphologically detectable siderophile microflora is extremely sparse here.

Thus, precipitation may, at least in part, be considered a purely chemico-physical process. However, it is obvious that it may be promoted by the effect of the flora on the environment. For the subsequent concentration of the fine-grained precipitate to the definitive ore formations, however, the flora may play a considerable part as a result, among other things, of its effect on the structure of the ground. Under limnetic conditions, however, it is exceeded by far in this respect by the fauna.

Also the formation of the final ore shapes must therefore be considered a physico-chemical problem. It is true that NAUMANN, 1922(c), reported on an alga that causes precipitation of iron in the form of an aggregate of pea ores. However, this is an exception, with no real significance for the comprehension of the problem of ore shapings.

IV. Terminology of Lake Ores

The different ore shapes may be grouped as follows:

I. Ores of Spherical Shape

Depending on the size, the ancient ore fishers talked about gunpowder ores, buckshot ores, and pea ores. These designations became introduced also into the scientific literature. For illustrations see Figs. 9-10.[1)] These ores may be characterized by Fe_2O_3 or by Mn_2O_3. Specific manganese ores, however, are the loose "soot balls". - For illustration see Fig. 11.

II. Discoidal Ores

Penny Ore.

III. Bean-Shaped Ores (182)

Illustration see Figs. 10, 12.

IV. Coil-Shaped Ores

Illustration see Fig. 13.

V. Angular Ores

With regard to size and general shape, they represent most of the above mentioned types; however, they are distinguished mainly by their angular aspect. Illustration see Figs. 10, 12.

VI. Tubular or Channel-Shaped Ores

Cp. Figs. 24, 45.

VII. Shield-Shaped Ores

Small cake ores.

VIII. Nostoc-Like Ores

It is formed directly by the growth of a Nostoc-like Myxophyceae. It resembles small cakes similar to pea-ore aggregates. - A very rare type. Has so far been found only in one case. For further details see E. NAUMANN, 1922(c).

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1) All these illustrations were carried out on gas-light paper, directly in natural size, as "shadow photographs". - Regarding the technique of this very efficient method, particularly for this kind of work, see further details in E. NAUMANN, 1915, 1917(a).

IX. Pipe Ores

May be defined as an aggregated coil or tubular ore. Compared with the above mentioned types, it is quite seldom. The author has never seen it. The designation originates from the older Swedish literature.

X. Cake Ores

They form large cakes on the lake floor, and may be of various origin. Illustration see Fig. 14. Their surface is either rough or - seldom - of dendritic structure. Illustration see Fig. 15.

* * *

The above mentioned ore shapes originate mainly from concretion processes. However, the initial material may be quite heterogeneous. Between the initial type and the accomplished ore therefore, on the whole, there exists no real parallelism. The following description of the formational conditions of lake ores will explain this in detail.

V. Ore Location in the Limnetic Zonation

The ore deposit lies typically eulittorally[1], and follows shorelines where sand and grit depositions are predominant. The vegetation of the sublittoral therefore is unimportant. Characteristic forms of eulittoral plants on ore deposits are mainly Isoëtes, then also Lobelia, as well as Subularia. - For the profile of an ore-bearing lake see Fig. 22.

Some typical pictures of the ore lakes of Småland are shown in (183)
Figs. 16, 18, 20-21. However, Figs. 17 and 19 show the normal physiognomy of non-ore-bearing lakes. It is true that in Fig. 19 the shore is stony,

1) Translator's note: The German "elitoral" would appear to be "eulittoral".

but covered with mud[2], and in Fig. 17, the lake is being grown over to become dry land, which is indicative of mud formation, but never in connection with ore formation. Compare also Figs. 68-69 which illustrate the littoral region of ore-bearing lakes where regulatory measures were applied.

The eulittoral occurrence of the lake ores appears to depend quite simply on the <u>ground-water conditions</u>, since at this level, the ground water from the surroundings seeps into the lake floor. Accordingly, the ocher-bearing mud deposit[3] shows the highest ocher content in the eulittoral. From there, the ocher-bearing layer becomes thinner both toward the littoral and toward the profundal. - Cp. the profiles shown in Fig. 23: (a) at the beginning of the ore deposit; (b) in its center; (c-d) transition toward the profundal.

This distribution of the ore in the eulittoral is usually markedly spotty. This points, of course, directly to its dependence on the ground-water conditions.

VI. Chemistry of the Lake Ores

Lake ores are either iron ores or manganese ores. However, even within the same lake, the chemical structure changes considerably, and there exists continuous transition between the extreme types. Compare the illustration on p. 48 where the chemical structures of the ore deposits of Lake Vidöstern have been compiled, on the basis of several hundred separate samples, in the form of 11 general samples which represent different parts

Translator's note:
2) Swedish "dy" = muddy lake sediment containing plant residues.

3) Swedish "gyttja" = watery lake-floor deposit with decaying plant and animal residues.

of the lake. Of these samples, Nos. 1, 6, 8, 10 and 11 may be designated as good-quality bean iron ore. Nos. 2, 5, 7, 8, 9, on the other hand, represent cake ore, and No. 3 a typical manganese ore. However, in other cases, the composition is more homogeneous. Compare the analyses from Lake Bolmen, p. 50. They refer to 22 general samples from different parts of the lake.

How these conditions may be explained will be shown more in detail in the following. For further details cp. also ASCHAN, AARNIO and VOGT.

VII. Iron Ores and the Shaping Problem

1. Principle of Concretion

Lake iron ores, on the whole, are concretions. Their eulittoral location, of course, requires a large amount of the respective initial material. The formations which are mainly involved as centers for the concretion may be grouped as follows:

A. Organic Material

Allolimnetic organic mud[4)] - decreases in the direction toward the profundal.

Autolimnetic organic mud[4)] - decreases in the direction toward the profundal.

Coprogenic formations - increase in the direction toward the profundal.

Skeletal residues of microscopic organisms: (184)

a) Littoral - decrease in the direction toward the profundal.

b) Pelagic - increase in the direction toward the profundal.

Skeletal residues of mollusks - decrease in the direction toward the profundal.

B. Inorganic Material

Sand - decreases in the direction toward the profundal.

Grit - decreases in the direction toward the profundal.

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4) Translator's note: Swedish "förna" = humus-forming plant and animal residues in plant communities.

It is obvious that an initial[5] material as the above mentioned must, in part, be considered as chemically indifferent. However, in certain cases, one must assume that even the initial material may have an active part in the precipitation - either by sorptive processes or by actual reactions. However, no research has as yet be done in this respect. Thus, for example, the plant material, owing to its content of tanning matter, and the mollusk shells because of their lime content, may react with iron solutions, etc. But, even though actual reactions <u>may</u> take place, at least initially, the concretional formation is nevertheless predominant during the subsequent growing of the ores.

2. Type of Ore Dependent on Initial Material

As mentioned before, the definitive shape of the ore depends not only on the structure of the initial material. Even its location in the ore-forming, ocher-bearing mud deposit (gyttja) is also of importance. Three different cases are possible here:

a) A thin layer of ocherous mud deposit lies over the ground which consists of uneven moraine material. The iron-bearing ground water trickles over the ground. - The concretion takes place here around individual grit grains, mainly in the form of ring-shaped precipitations. Effect: Mainly penny-type ores.

b) A thicker layer of ocherous mud deposit with dispersed initials. The iron-bearing ground water trickles upon this layer. - Effect: In the surface layer, penny ores, but further down, spherical ores, etc.

c) As b), however the iron-bearing ground water rises from below. Effect: As in b), but the iron precipitation is oriented in the opposite sense.

5) Translator's note: German "Initial" = Magmatism of a geosynclinal period within an orogenic cycle. - Hereinafter used for any inorganic and even organic material that may serve as a substrate or nucleus for ore formation or concretion.

Different Initial Materials

After this general introduction, the different initial materials and their significance for the formation of the ore deposits will be dealt with more in detail. We distinguish:

3. Allolimnetic Organic Mud (Förna) as Initial Material

This is a special case which, so far, has been observed to a major extent only in a small forest lake. However, the problem of the shape formation appears here in a strikingly simple manner, so that this case might be designated as "classic". I put it therefore at the beginning of the following summary.

In the respective forest lake, a fine penny ore was found, yet (185)
also the most differing ore shapes of the pipe and channel types, etc. In the eulittoral, they appeared rather complete; toward the shore, however, they appeared in all stages of the status nascendi. It was apparent that all these ore shapes might quite simply be explained by a mineralization, mainly of the periodically cast-off pine-bark fragments. Compare Fig. 24 which shows the different ore shapes in statu nascendi.

As mentioned before, this type in its purity must be considered as very seldom. However, it is obvious that otherwise - as interspersion - it appears rather frequently.

4. Sand and Grit as Initial Material

In our lakes of the lime-deficient moraine regions, this material is chiefly involved in the formation of the different ore shapes.

The sand grains play a major part. The whole concretion process may be easily observed microscopically. Fig. 25 shows it in a general diagram. As may be seen therefrom, the deposit of the fine-grained precipitate starts in small cracks and other capillary cavities. The precipitation usually forms simple rust stains. Other structures - cp. Fig. 26 - are seldom. Iron bacteria cannot be detected morphologically, although in exceptional cases the structure of the iron precipitate might resemble a Siderocapsa. - Mud samples, reproduced photomicrographically, directly on gas-light paper, provide a good view over the mineralization process. Cp. Figs. 27-28. (Quartz appears black because of the photographic technique, with increasing iron precipitation, white).

The mineralization of the sand grains yields primarily a gunpowder-type ore which, however, eventually may grow further. - Conversely, the grit grains produce already primarily the most differing ore types, mainly of angular shapes. - Penny ore forms mainly in the uppermost layer of the ocherous mud deposit. For typical pictures in statu nascendi see Fig. 29.

Concretion may, of course, start also on even coarser material. Cp. Figs. 30-31 which show a profile with ore formation on coarser stone material. Occasionally, this may result in a type of ore cakes.

5. Coprogenic Formations as Initial Material

The dominant part played by coprogenic material in the form of dung balls etc., for the physiognomy of limnetic depositions was first demonstrated by E. NAUMANN, 1917(a). For basic questions therefore see his report.

The coprogenic material occurs mainly as dung balls or aggregates - occasionally in the form of larval tubes etc. Cp. Figs. 32-35. Fig. 32 (186)
provides a schematic illustration of coprogenic material in about natural size. To the left are the dung balls, to the right larger aggregates thereof. Figs. 33-35 illustrate photomicrographs (x 20) of suspension residues.

The iron enrichment may be quite important, and results primarily in a gunpowder-type ore. If this kind of ore is treated with HCl, the dung balls reappear. Compare Figs. 36-37 which show an ore sample in its original condition and after treatment with HCl.

The iron enrichment may be quite diffuse or concentrated on certain centers. Probably, complicated diffusion processes, the geological significance of which LEISEGANG reported on in detail, are involved. In this manner, of course, the most complicated ore shapes or structures may occur. Cp. Figs. 38-41.

6. Initial Material Produced by the Mechanical Effect of Plant Roots on the Soil

Occasionally, the elements of lumpy or tubular structures may constitute abundant iron stores. Cp. Figs. 42-43. The most diverse ore shapes may form in this manner; generally, however, "root scars" easily reveal their initial material. Compare Figs. 44-45 which illustrate ore material of the penny and bean or tubular types.

7. Autochthonous Organic Mud (Förna) as Initial Material

Its importance decreases toward the profundal, and it therefore plays no major part in the ore formation of the eulittoral. Otherwise, the iron concentrates quite heavily on all kinds of tissue fragments. Cp. Fig.46.

A special case of great interest is the mineralization of the *Isoëtes* spores. Since, occasionally, *Isoëtes* is dominant on ore deposits, under certain conditions even this initial may play a part. Cp. Fig. 47.

8. Microskeletons as Initial Material

Almost any microskeleton may serve as initial material for concretion. Occasionally, this process may even simulate participation by organisms.

Cp. Fig. 48. However, it is very significant that concretion proceeds also in and on quite empty shells. It may also be found on spongial spicules, where it may be demonstrated particularly clearly how the fine-grained precipitate with elementary particles of maximum about 1 μ size accumulates almost in the manner of a thigmotactic reaction. It might not be possible to more clearly demonstrate the physico-chemical principle of this concretion formation. - Cp. Fig. 49. - It is obvious that these conditions must be considered as significant also for the proper explanation of many iron skeletons of siderophile organisms.

9. Calcareous Shells of Mollusks as Initial Material

This is a special case which plays a part only quite locally, in limestone regions, where also plenty of iron-bearing moraine material is available. (187) To comprehend the nature of the huge ore formations in the lime-deficient lakes of South and Central Sweden's primitive mountains, this special case need not be considered. So far, this type of initial material has been recorded only for quite insignificant ore deposits in the Furesø, Denmark (by WESENBERG-LUND) in the Madü Lake (by WELTNER), and in the Spree (by KOLKWITZ, NAUMANN).

Even an initial material of this texture may produce very differing ore types, depending on the condition of the initials. Fragments of snails and mussels provide an angular ore, whole shells of Valvata, a bean ore, etc. Compare Figs. 51-53 which illustrate silhouette pictures of natural size.

10. Principle of Total Ground Mineralization

If the iron-bearing ground water encounters a more or less thick layer of mud deposit (gyttja), with separately bedded initials, the resulting effect is the above discussed typical ore formation. However, if there is no mud-deposit layer over the ground, or only a scarce one, the very ground surface may be completely mineralized. This has been observed on sand and gravel soils, as well as on clayey soils. It results in a technically inferior ore of the cake type. Cp. Fig. 54.

* * *

The above survey has shown that a great variety of initial materials may participate in the origin of ore formations. Moreover, one and the same initial material may produce the most variable ore types.

However, apart from special cases, the main initial materials are sand, grit, and coprogenic material. This initial material, however, is not available in the same manner in every ore lake. If unsorted moraine material lies along the shore, it will make a large contribution to the ore formation. However, if the shores consist of sand, this is the material that will serve as initial. If they are clayey or if the ore deposits, because of the soil profile, are rather distant from the shore, the coprogenic material will be dominant. Consequently, two different types of ore deposits will be encountered in any case: first, where angular ore is primarily dominant because of the unsorted moraine material and, secondly, where rounded forms predominate. Cp. Fig. 55 with Fig. 56, Fig. 57 with Fig. 58. From a technical viewpoint, of course, the last mentioned type of ore is preferable.

VIII. Manganese Ores and the Problem of Shapes

Primarily, the manganese ores may originate in the same manner as the iron ores. This has been demonstrated at least for the soot balls. Cp. Fig. 59. Generally, however, the formation of the manganese ores is related only to the secondary changes of the iron ores.

IX. Secondary Changes of Ore Deposits (188)

The simplest type of secondary changes is the "transition" of iron ores to manganese ores, i.e. the precipitation of manganese occurs with iron ore as initial. The final product are typical soot balls. Cp. Figs. 60, 61-62 (Chemical Analysis , p. 48, No. 3). The iron deposit is thus transformed into a manganese deposit. - Chemically, this may be explained by the principle of the separate precipitation of iron and manganese, the geological significance of which was elucidated by VOGT.

However, far more complicated changes are required for a conglomerate formation where the iron ore is cemented together by manganese ocher. In this manner, very complicated stratifications form in the ore deposits. This results, purely secondarily, in substantial deposits of cake-type ores. Cp. Fig. 63. Chemische Analysen (Chemical Analyses), p. 48, Nos. 2, 5, 7, 9. - Formation of soot balls may, but is not required to, precede in this case. Cp. Fig. 64.

The formation of cake ore is, so to say, the mature stage of ore formation. Probably, however, - cp. the dissolution structures of the cake ore illustrated in Fig. 65 - the manganese ocher can be redissolved, with a resulting regeneration of the degenerated ore deposit.

X. Microscopic Structure of the Ore

The ores generally exhibit a concentric structure which is dependent either on growth conditions or on diffusion processes in the original initial material.

The initial material as such generally cannot be demonstrated in its original condition. Quartz grains, siliceous skeletons etc, remain, of course, but the petrographic structure of the grit grains collapses under the effect of penetrating iron solutions, and only certain resistant minerals remain. Compare Fig. 66 which shows the removal of the binding material in a quartzite. (photomicrograph x 50; quartz is black because of the photographic technique, iron is white). - This makes also reconstituting the development of the ore types from ground (polished) preparations impossible. Only a comparative study of the material _in statu nascendi_ - as carried out in the present case - made it possible to reach the objective.

With regard to the finer structure, of course, the most diverse "microfossils" may be detected in the ore grains, even though they may be quite isolated. It is significant that the morphologically detectable siderophile organisms are scarcely involved. The bulk of the ore is formed by Fe_2O_3 or Mn_2O_3 which, however, microscopically, appears in a form that might simulate bacteria. Cp. Fig. 67. These "cocci", about 1 μ, - which vividly remind a very small _Siderocapsa_ - may actually be demonstrated in a purely chemical manner. Probably, they are mainly mere flocculation (189)
products. Their structure might, at least in part, be explained by the fact that the colorless nucleus consists mainly of flocculated humus colloids, surrounded by Fe_2O_3. However, some must probably be considered actual bacteria in this instance.

Of course, the demonstration that bacteriod structures may form in this manner must be considered as very significant in principle. This clearly shows, among other things, the necessity to deal very carefully with the morphological demonstration of bacteria in old and even more recent deposits.

XI. Quantitative Conditions of Lake Ores

Detailed information regarding lake ore quantities is available for the Bolmen, Unnen, and Vidöstern lakes in Småland. According to these investigations - which were carried out with the use of LARSSON's quantitative ore tester - the amounts of ore are:

in Lake Bolmen	409,321 t of good iron ore
in Lake Bolmen	349,323 t of sandy iron ore
in Lake Unnen	205,962 t of good ore
in Lake Vidöstern	383,916 t of good ore

For an example of an ore map see Plate 3. The production of ore (Swedish "malm") per square metre of ground surface is indicated by a sign system (see map). Iron ore is indicated by solid lines, manganese ore by broken lines.

It is evident from this that substantial quantities are involved, especially if the occurrence of the ore which is restricted to the eulittoral is taken into account.

XII. Age of Lake Ores

So far, only few investigations have been carried out in this respect. However, SUNDELIN estimates the age of the Småland ores at about 2500 years, and correlates their first formation with the enormous increase in the high-moor area in this province, which took place at that time due to climatic conditions.

However, the lake ores keep growing. As already explained, at this mature ore stage the eulittoral is practically continuously covered with cake ore. However, a regeneration may follow this degeneration.

If the ore deposits are exploited industrially, this degeneration is of course, prevented and new, "good" iron grows again. The old ore fishers of Sweden also believed that an ore deposit could be fished again about every 30th or 50th year. However, this is most likely exaggerated. Yet, no reliable empirical data about this significant question are as yet available. Moreover, it is obvious that a general statement in this regard cannot be made because of the changing ground-water conditions. Only monographic studies will provide relatively correct answers for specific cases. But until such material becomes available, any detailed scientific discussion regarding the regeneration of ore deposits is impracticable.

XIII. Drained and Regulated Ore Lakes (190)

From the location of the lake ores within the limnetic zonation, it is evident that they are dependent on any water regulation. If the water level is lowered, the ore deposit becomes silty and grown over by plants. If it is raised, the ore deposit likewise becomes silty. In either case, industrial utilization of the ores is complicated. Moreover, silted-up ore deposits might easily disintegrate.

Figs. 68-69 show some characteristic pictures of a rather heavily drained ore lake in the Province of Småland. It is evident from these figures that completely drained ore deposits will constitute a very unfertile soil.

XIV. Homologies of Lake Ores

This question has been dealt with repeatedly - mainly by BEYSCHLAG, KRUSCH and VOGT. One may therefore refer to the respective literature. However, for the comprehension of the concretion process generally, or regarding the stratigraphy of the ore deposits, the investigations we carried out have undoubtedly brought forth new information in many respects. Above all, one might refer to the strange enrichment processes that occur in the coprogenic material that is often available in massive quantities.

XV. Occurrence of Lake Ores in South and Central Sweden

Based on archive records regarding the ancient lake-ore industry in Sweden, Plate 4 shows a map of the occurrence of the lake ores in Sweden. For South and Central Sweden, it provides a rather good view of the lake ore distribution and its relation to the geological conditions in general. Since the limnology of Northern Sweden is scarcely known, it was not possible to provide a similar map.

This map of South and Central Sweden contains the following:

1. The area below the marine limit is shown in blue.
2. The areas of the calcareous mountains are shaded with oblique lines.
3. The areas of the lime-rich soils are shaded with oblique, broken lines.
4. Lake-ore findings are marked by dots.
5. Bog-ore findings are marked by crosses.

Taking into consideration the regional distribution of the ores in South and Central Sweden, the following results:

1. The ores belong in the first place to the primitive mountain areas above the marine limit.
2. Their distribution correlates therefore positively with
   a) the main development of the silicate rocks,
   b) the main development of the gravel deposits,
   c) the main development of the electrolyte-deficient humus waters.
3. Below the marine limit, the ores occur seldom.
4. In the calcareous mountains, there are no ores at all.
5. Their distribution therefore correlates negatively with
   a) the main development of the calcareous rocks, (191)
   b) the main development of the clay deposits,
   c) the main development of the electrolyte-rich clear waters.

III. Origin and Occurrence of Bog and Meadow Ores

I. Investigational Area

The same investigational area was used as for the lake ores. - However, the investigational technique in this case is much simpler, and may be restricted at the site to the digging up of representative profiles.

II. Terminology of Bog Ores - Their Formational Principle

The bog ores may be subdivided as follows:

I. Ores Precipitated on the Ground Surface, that is, ores which are dependent on ground water that emerges as a spring.

These ores occur only as loose ocher formations.

II. Ores Precipitated in the Ground, that is, ores that are dependent on a ground water which, during its movement, reaches the oxidizing horizons of the upper soil layers.

These ores are to be grouped as follows:

1. Granular ores:
   a) of the angular type, see Fig. 71
   b) of the oolith type
2. Cake ores:
   a) Slag-shaped structure, see Figs. 72-73
   b) Oolith-shaped structure, see Fig. 79

III. Formational Principle of Bog Ores

I. Ore Precipitated on the Ground Surface

It may be subdivided genetically as follows:

1. Ocher formations precipitated essentially in a purely physico-chemical manner. Generally, they are very resistant, and therefore usually constitute permanent formations.

2. Ocher formations precipitated mainly with the cooperation of organisms. Generally, they are not very resistant, and therefore usually constitute only transitory formations. In their precipitation, the following factors must be distinguished:

1. Effect of higher plants on the environment. - A whole series of bog plants (including Callitriche species, Ranunculus flammula, Glyceria species etc.) exhibit real iron encrustations on their leaves.

2. Microscopic plants as a specifically iron-precipitating factor. - Here - mainly represented by bacteria - they often are of dominating significance. Cp. E. NAUMANN, 1922(a).

II. Ores Precipitated in the Ground

The precipitation of iron or manganese, in this case, must be considered mainly as a purely physico-chemical process.

IV. Problem of Shaping

This problem, of course, exists only for ores precipitated in the ground. Ores precipitated on the ground always remain at the ocher stage, and therefore - probably because of the compact stratification of the ocher - do not go over into other shapes.

For the deep-precipitated bog ores, the initial material is supplied mainly through the effect of the plant roots on the soil structure. This kind of soil material, penetrated by finest rootlets, is illustrated in natural size in Figs. 77-78. Hence, on more superficial horizons, an angular ore usually forms, while in deeper horizons cake ore of slag-shaped structure is produced. Cp.Fig.75. The superficial horizon,of course,may be saturated intermittently, the deeper one continuously, with the iron-bearing ground water. Cp. Fig. 76. - Oolith formations are found only seldom.

However, it is of great significance that - according to observations made on material in statu nascendi - they can actually form in this manner. The microstructure of the oolith-type cake ore (cp. Fig. 79) is illustrated diagrammatically in Fig. 80.

V. Occurrence of Bog Ores

In the above described type of landscape, bog ores occur wherever iron-bearing ground water either emerges as a spring or is in contact with the upper soil horizons. Compare Figs. 81-92 where typical ore locations are shown. They may therefore be found in the most differing plant-biological associations; the designation bog ore therefore is not quite correct. The condition of the plant formation apparently exerts no effect. However, the plants may be heavily damaged by the ore formation - in the case either of a superficial ocher formation which submerges everything, or in case of a deep-precipitated cake formation which damages the vegetation according to the hardpan principle.

VI. Chemistry of Bog Ores

In the same manner as the lake ores, the bog ores also occur as iron or manganese ores. For further details see VOGT, 1906.

Whether the bog ores undergo secondary changes similarly to the lake ores, is still unknown. However, it is improbable. The very bog-ore precipitation principle causes the complete shutting-off of the water that circulates in the ground. It appears probable that the bog ores must actually have a much higher stability than the lake ores. However, further investigations will be required to settle this question.

VII. Quantitative Conditions of Bog Ores

(193)

The bog ores occur only batchwise, and each ore deposit quite often contains only a few tons, or even less. Very often, the formations are completely isolated. However, if they appear *in statu nascendi*, this is immediately apparent by the ocher-colored water which emerges from the dug-up profiles.

VIII. Homologies of Bog Ores

Regarding the homologies of bog ores, see above all the detailed description in the handbook of BEYSCHLAG, KRUSCH and VOGT.

IX. Occurrence of Bog Ores in South and Central Sweden

The distribution of the bog ores correlates positively to that of the lake ores. Compare the map on Plate 4, as well as the above explanation about the regional distribution of the lake ores in South and Central Sweden.

However, since the bog ores have never played a major industrial role, it is obvious that, in this respect, the map must be considered as incomplete.

IV. Relation between Bog Ores and Lake Ores

Bog ores and lake ores are in a sense two facies of the same process - the iron removal from the iron-bearing ground water. They therefore also correlate typically in their distribution. Their high frequency is characteristic of our lime-deficient moraine regions, characterized by high-moor formations, with extensive grit and sand depositions.

V. Practical Importance of Lake and Bog Ores in Sweden

The metallurgical industry in Sweden goes back to the time of Christ's birth. The original raw materials were then provided by the bog ores. Later on, it developed to the lake-ore smelting. At that time, it was florishing mainly in the province of Småland, and out of its industrious population, who was able to adjust to any conditions, developed the hard occupation of the ore fisher.

Ore fishing in the lakes of Småland was still in full swing as recently as the 1860s. However, now it has practically disappeared.

Ore fishing took place, preferably, from the ice. Cp. Figs. 99-102.

However, this ancient industry now has almost disappeared. Occasionally it is still practiced, mainly to protect old privileges. Regarding (194) the amount of dredged-up lake ores since the 1860s, when this occupation was still alive, the Table on page 171 (which refers to the average tonnage per year) provides further information.

Out of the numerous smelting works in Sweden, which once took part in the iron production from lake ores, however, at present, practically only Åminne on Lake Vidöstern is still in operation. Dredging, of course, is now done by machinery. Figs. 97-98, 103-110 illustrate the present works at Åminne. The iron that is produced there is used for foundry purposes, and has proved to be a high-grade iron of excellent quality.

The fact that useful iron deposits lie on the lake bottoms of our lime-deficient ancient mountains, which could motivate a different position of the lake-ore industry, even in our days, should be readily apparent from the above said. Some day in the future, we may actually be forced to turn again to these historic findings.

Lund (Sweden), April, 1919.