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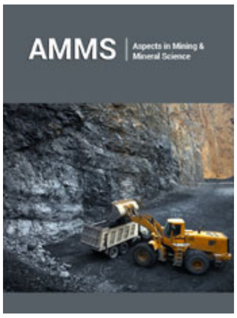
Main Precambrian and Paleozoic Mineral Resources of Estonia

Alvar Soesoo*

Department of Geology, Tallinn University of Technology, Estonia

ISSN: 2578-0255



***Corresponding author:** Alvar Soesoo, Department of Geology, Tallinn University of Technology, Estonia

Submission: April 20, 2021

Published: May 12, 2021

Volume 6 - Issue 3

How to cite this article: Alvar Soesoo. Main Precambrian and Paleozoic Mineral Resources of Estonia. Aspects Min Miner Sci. 6(3). AMMS. 000639. 2021.
DOI: 10.31031/AMMS.2021.06.000639

Abstract

Estonia is rich in mineral resources. For example, oil shale usage has over 100 years of history and Estonia holds, the largest in Europe, unused sedimentary phosphate rock reserves, about 3 Billion metric tons ore (ca 819 Million metric tons of P_2O_5). The phosphate content in fossil shells (phosphorite) ranges 35-37 wt% P_2O_5. These shells are relatively enriched by rare earth elements, where the total rare earth metals reach 3600ppm. The phosphates are overlain by metal-enriched black shale-graptolite argillite. Calculated tonnage of elements in the black shale is uranium-5.6656 Million tons (6.6796Mt as U_3O_8), Zinc-16.5330Mt (20.5802Mt as ZnO), vanadium-47.7538Mt, molybdenum-12.7616Mt (19.1462Mt as MoO_3) and thorium tonnage in between 0.213-0.254Mt. Estonian oil shale-kukersite deposits cover up to 5,000km^2. The total kukersite resources in Estonia are estimated to be about 4.627 Billion tons. Several metal occurrences are known in the Paleoproterozoic basement of Estonia. In NE Estonia, magnetite-gneisses (up to 45 % total iron), sometimes enriched in Mn (up to 6 wt%) are found in Jõhvi complex and in several locations elsewhere. Historical drillings have shown that the complex of magnetite-rich rocks is about 100m thick, and the reserves of iron ore (Fe over 25%) are about 355 Million tons (calculated to depth of 500m), 629 Million tons if calculated to the depth of 700m and 1500 Million tons if calculated to the depths of 1000m. However, this needs to be confirmed by modern exploration.

Keywords: Earth resources; Iron ore; Phosphorite; Oil shale; Carbonate rocks; Black shale; Rare earth elements; Estonia

Introduction

In terms of the structural framework, Estonia is situated in the central part of Baltica paleocontinent and is a part of the East European Craton. The crust consolidated during the Svecofennian Orogeny in the Paleoproterozoic. The crystalline rocks are covered by Late Proterozoic (Ediacaran) to Lower Paleozoic (Cambrian to Devonian) sedimentary rocks, with thicknesses from 100m (in the north) to 800m (in the south and SW Estonia). Precambrian rocks do not outcrop anywhere in Estonia but are present in the subsurface. The surface of the crystalline basement dips gently to the south. The boundary between the Neoproterozoic to Paleozoic sedimentary sections of Baltica and the Precambrian Fennoscandian Shield extends along the seabed of the Finnish Bay of the Baltic Sea in northern Estonia. Estonia is rich in mineral resources. For example, oil shale usage has over 100 years of history and Estonia has the biggest in Europe phosphate resources. In this review I present an overview of the main mineral resources, especially those resources which may meet the future needs. Sand, gravel, muds, peat and some building materials are left out from this review.

Metals in the Precambrian Basement

The Estonian Precambrian basement can be considered as a southern continuation of the Fennoscandian Shield rock complexes of the East European Craton. Based on geophysical and petrological studies, the Estonian Precambrian complexes can be divided into two major geological units–the North Estonian amphibolite facies unit and the South Estonian granulite facies unit [1-6]. Magnetite-gneisses (up to 45 % total iron), sometimes rich in manganese (up to 6 wt%) are found in Jõhvi complex, NE Estonia and in several locations in northern Estonia

(Figure 1). Historical drillings have shown that the complex of magnetite-rich rocks is about 100m thick, and the reserves of iron ore (Fe over 25%) are about 355 Million tons (calculated to depth of 500m), 629 Million tons if calculated to the depth of 700m and 1500 Million tons if calculated to the depths of 1000m [3,5]. These estimates, however, are based on very limited data and need to be assessed by drilling in the future [7,8]. Significant anomalies of sidero-chalcophile sulphide-graphite-bearing gneisses also occur in northern Estonia where the total concentration of Cu, Pb and Zn can be as high as 5.6 %.

Earth Resources in the Lower Paleozoic Sedimentary Section

Phosphorite

Estonia holds, the largest in Europe, unused sedimentary phosphate rock reserves (Figure 1), about 3 Billion metric tons (ca 819 Million metric tons of P_2O_5; [9,10]. The Estonian shelly phosphate rocks are friable to weakly cemented bioclastic quartz sandstones deposited in a shallow marine shoreface environment with a variable content of phosphatic brachiopod shells detritus. These sediments deposited approximately 488 million years ago. The content of fossil shells ranges from 5-10% to 80-90 vol%. Brachiopod shells and enriched detritus contain up to 35-37 wt% P_2O_5. Present studies have revealed relatively enriched, but variable content of Rare Earth Elements (REE) in phosphate shells. For example, La in single shells ranges 50 to 550ppm, Ce–40-1200, Pr–4-170, Nd–20-800, Sm–3-180 and Gd–4-135ppm. The total REEs can reach 3600ppm, ranging in average from 1000 to 2300ppm [10]. At the moment the Estonian phosphorites cannot regarded as an economic REE source, but considering REEs as a co-product of phosphorous production, it may economically be feasible. Relying on the vast phosphorite reserves in Estonia, the critical nature of both the phosphorus and REEs for the European economy and security, it may be a worthwhile opportunity to develop these resources into production at the global scale. Considering that future possible mining operations will have an annual production of 5Mt tons of ore, the estimated annual total REE amounts will be 720 tons at REE^{tot}=1200ppm, or 900 tons at REE^{tot}=1500 ppm. In addition, about 120 tons of uranium and 27 tons of thorium can be extracted each year [11].

Oil shale

The Estonian oil shale–kukersite - with mining history over 100 years, is a Late Ordovician sedimentary rock formed some 460 million years ago. Kukersite deposits are possibly the world's second highest-grade (after the Australian torbanite) oil shale deposits with its organic content from 15% to 55% (calorific value is 15MJ/kg (3,600kcal/kg) and its Fischer Assay oil yields of 30 to 47%. The largest kukersite deposits in Estonia–the Estonian and the Tapa–cover about 3,000km^2 (Figure 1). The mined kukersite resource in 2019 was about 12 128 thousand tons. The total kukersite resources in Estonia are estimated to be about 4.627 Billion tons [7]. This amount includes about 1.25 Billion tons of economically proven and probable reserves and 3.378 Billion tons of passive reserves. So, the Estonian kukersite represents about 1.1% of global and 17% of European oil shale resources. For some last decades the mining limit has set by government to 20 million tons per year. During the last years the active mining was considerably below that limit. Today, about 30% of this resource is still lost during underground mining. In the frame of increased global awareness of environmental protection, climate issues and sustainable development, the rising technical and socio-economical question is how to use oil shale in cleaner, more sustainable manner in production of more efficient and economically valued products [8]. The direct combustion of oil shale in power plants is not economically and environmentally plausible in the future. However, oil shale has been the ground for Estonian energy independence, so a new technological breakthrough is needed in the oil shale sector in order to support energy independence.

Graptolite argillite (Black shale)

Although Estonian kukersite is low in metals, there is another type of oil shale known as graptolite argillite (historical term Dictyonema argillite/shale). The graptolite argillite is a kind of black shale of sapropelic origin, which is characterized by high concentrations of a number of metals, for instance: U (up to 1200ppm), Mo (1000ppm), V (1600ppm), Ni and other heavy metals, and the rock is rich in N, S and O [12,13]. The calorific value of the rock ranges from 4.2–6.7MJ/kg and the Fischer Assay oil yield is 3-5 %. During the Soviet era, the graptolite argillite was mined for uranium production at Sillamäe, NE Estonia, between 1948 and 1952. A total of 22.5 tons of elemental uranium was produced. Between 1964 and 1991, approximately 73 million tons of graptolite argillite was mined and piled into waste heaps from a covering layer of phosphorite ore at Maardu, near Tallinn. The calculated natural reserve of Estonian graptolite argillite is about 65-70 Billion tons [12]. GIS-based metal content calculations, which are based on data from more than 400 drill cores provide approximate total amounts for certain elements (Figure 1). For instance, the calculated tonnage of uranium is about 5.6656 Million tons (6.6796Mt as U_3O_8), zinc tonnage is 16.5330Mt (20.5802Mt as ZnO), vanadium tonnage is 47.7538Mt, molybdenum about 12.7616Mt (19.1462Mt as MoO_3) and thorium tonnage in between 0.213-0.254Mt [11,12]. Western Estonia has the highest potential for these elements, especially for U and Mo production. It is important to note that due to the neighboring geological positions in cross-section of the graptolite argillite and phosphate ore, the future mining activity can be complex. There are no easy extraction technologies that can be applied on only one of those resources separately. Both the graptolite argillite and phosphorite need to be treated as a complex multi-resource. However, since a simple, environmentally-friendly and economic technology has yet to be developed for the co-extraction of most of the enriched elements from the graptolite argillite, its economic value remains still theoretical.

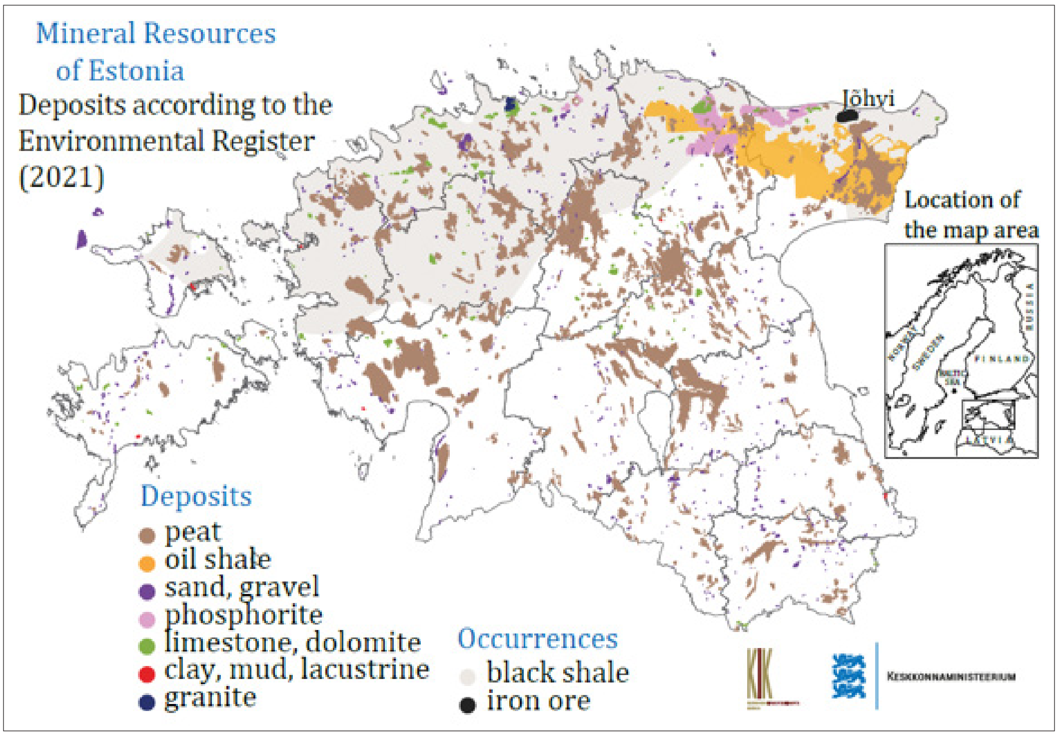


Figure 1: Sketch map of major mineral resources of Estonia. Compilation by the Ministry of Environment of Estonia.

Carbonate rocks

Carbonate sedimentary rocks-limestones and dolomites (dolostones) - are widespread within the rock sections of the Estonian Paleozoic basement. These carbonate sediments were deposited about 470-360 Million years ago in a sea environment of the Baltica paleocontinent. In general, Estonian dolomite most likely belong to the shallow-water environment and, in general, with the exception of the marginal parts of the paleobasin, represent the uppermost sediments of the regressive phases of sedimentary cycles. Sediments of deeper environments are usually not dolomitized. Dolomite as well as limestone has been and still is an important raw material in Estonia and it is used for different purposes locally and abroad. Historically, these carbonate rocks were used in construction for centuries, in medieval ages the usage of carbonate rocks increased remarkably, and they became the main construction material in castle and town building. The carbonate rocks from coastal quarries and stone quarries were exported to Germany, Russia, Latvia and Scandinavia. The dolostone (total of technological, construction, filling and other exploitation groups) mining in 2019 was 802 thousand m^3. About 86% of the mined dolostone was used in building construction activities. The active resources of the Estonian dolostones as calculated at 31.12.2019 are as high as 88 960 thousand m^3, while active reserves are 201 211 thousand m^3 and passive reserves are about 83 299 thousand m^3. There is research conducted on possible new application of dolostone in areas like SO_2 or CO_2 capture and modification of N-fertilizers [14]. The limestone mining in 2019 was 2342 thousand m^3. Vast amount of the mined limestone was used in building construction activities. The active resources of the Estonian limestone as calculated at 31.12.2019 are as high as 215 955 thousand m^3, while active reserves are 310 049 thousand m^3 and passive reserves are about 490 978 thousand m^3.

Conclusion

a. Estonia holds the largest in Europe, unused sedimentary phosphate rock reserves, about 3 Billion metric tons ore (ca 819 Million metric tons of P_2O_5). The phosphate content in fossil shells (phosphorite) ranges 35-37 wt% P_2O_5. The ore is relatively enriched by rare earth elements, where the total rare earth metals reach up to 3600ppm.

b. The phosphates are overlain by metal-enriched black shale–graptolite argillite. Calculated tonnage of elements in the black shale are: uranium-5.6656 Million tons (6.6796Mt as U_3O_8), Zinc- 16.5330Mt (20.5802Mt as ZnO), vanadium-47.7538Mt, molybdenum-12.7616Mt (19.1462Mt as MoO_3) and thorium tonnage in between 0.213-0.254Mt.

c. The Estonian oil shale deposits cover up to 3,000km^2. The total kukersite resources in Estonia are estimated to be about 4.627 Billion tons.

d. Several metal occurrences are known in the Paleoproterozoic crystalline basement of Estonia. In NE Estonia, magnetite-gneisses (up to 45 % total iron), sometimes enriched in Mn (up to 6 wt%) are found in Jõhvi complex and in several locations elsewhere. Historical reserve estimates of iron ore (Fe over 25%) are about 355 Million tons (calculated to depth of 500m), 629 Million tons if calculated to the depth of 700m and 1500 Million tons if calculated to the depths of 1000m.

e. The carbonate rocks are largely used in Estonia. Dolostone mining in 2019 was about 802 thousand m^3. The limestone mining in 2019 was 2342 thousand m^3.

Acknowledgement

This study was supported by ERDF and Estonian Research Council via project RESTA20 to TalTech “Genesis and economically valuable metals in polymetal sulphide mineralizations in Precambrian of Estonia“.

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