Kukersite Oil Shale

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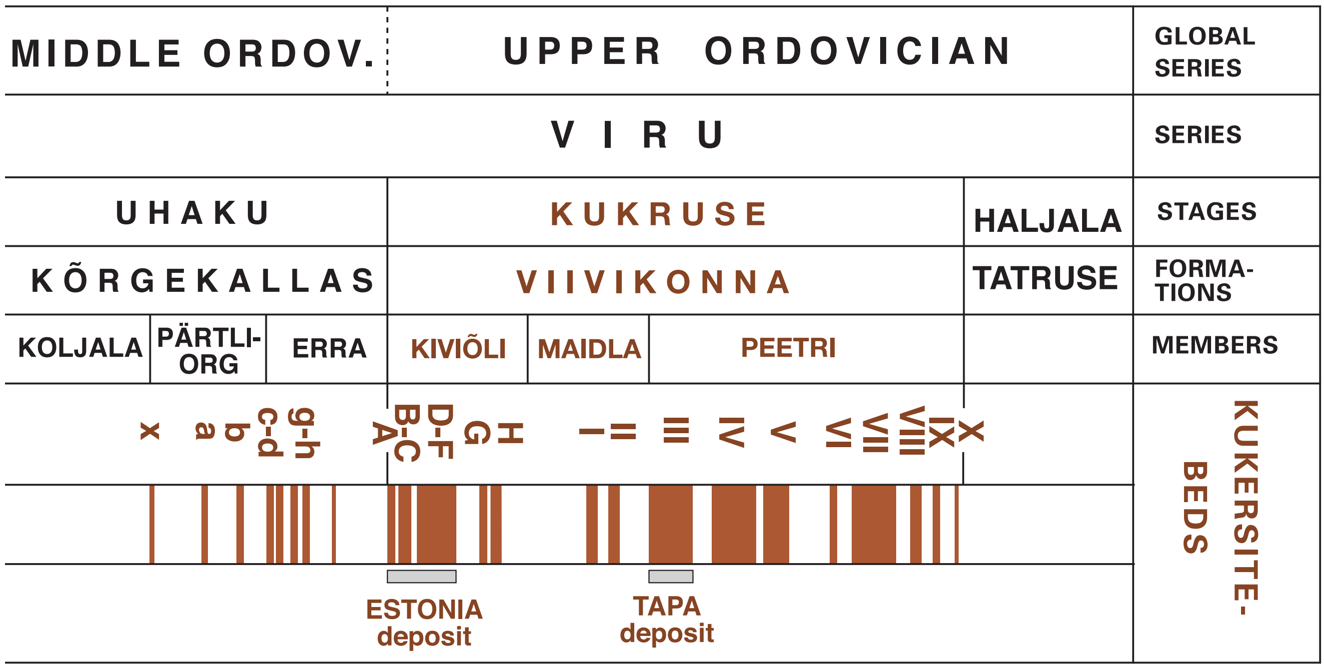
KUKERSITE OIL SHALE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KUKERSITE-BEDS
ESTONIA deposit
TAPA deposit

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KUKERSITE OIL SHALE

Tallinn 2007

Kukersite oil shale.
MTÜ GEOGuide Baltoscandia. Tallinn, 2007.

ISBN 978-9985-9834-2-3

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Front cover:	Estonia mine	
Back cover:	Oil shale seam B with bryozoans (photo by Allan Liivamägi)	

KESKKONNAINVESTEERINGUTE KESKUS

Release of this booklet in English was co-financed by Environmental Investment Centre, Estonia. It was previously published in Estonian and Finnish languages under the INTERREG IIIA Southern Finland and Estonia programme.

In March 2006, a press release announced that 1 billion (10^9) tonnes of oil shale had been produced in Estonia. It had taken 90 years to reach that amount. Oil shale was first mined in 1916 and sent for investigation to Petrograd. This date is recognized as the beginning of the production of oil shale in Estonia.

What is oil shale?

What is oil shale and why has it attracted people's attention for almost a century? In general, oil shale is a rock that comprises so much organic matter that it will burn. As there is no generally acknowledged definition of oil shale, it is usually classified as an argillaceous (or carbonaceous), fine-grained, sedimentary rock, in which solid organic matter or kerogen must form at least 5 to 25%. Like coal, oil shale can be used as a fuel without any preliminary processing. Oil is derived by complex chemical processes. In Estonia, there are actually two organic-rich burning rocks: graptolitic argillite and kukersite oil shale.

Graptolitic argillite

Graptolitic argillite, also known as Dictyonema shale or Dictyonema argillite, and locally known as the "frog's plate", is a dark, blackish- or greyish-brown, fine-grained claystone. Its organic-matter content reaches 15 to 20%. The rock owes its complicated name to the Lower Palaeozoic marine organism – graptolite *Dictyonema*. Its initial name, Dictyonema slate, is inaccurate on two counts. First, it is not a real slate clay belonging to metamorphic rocks. Second, according to the systematic revision in 1980s, the fossils in the rock are not graptolites

Lower Ordovician black shale cropping out in the temporary basement excavation of Kumu Art Museum, Tallinn from the genus *Dictyonema* but representatives of the genus *Rhabdinopora*. However, the terms *Dictyonema shale* or *Dictyonema argillite* are too strongly rooted in Baltoscandia to be replaced.

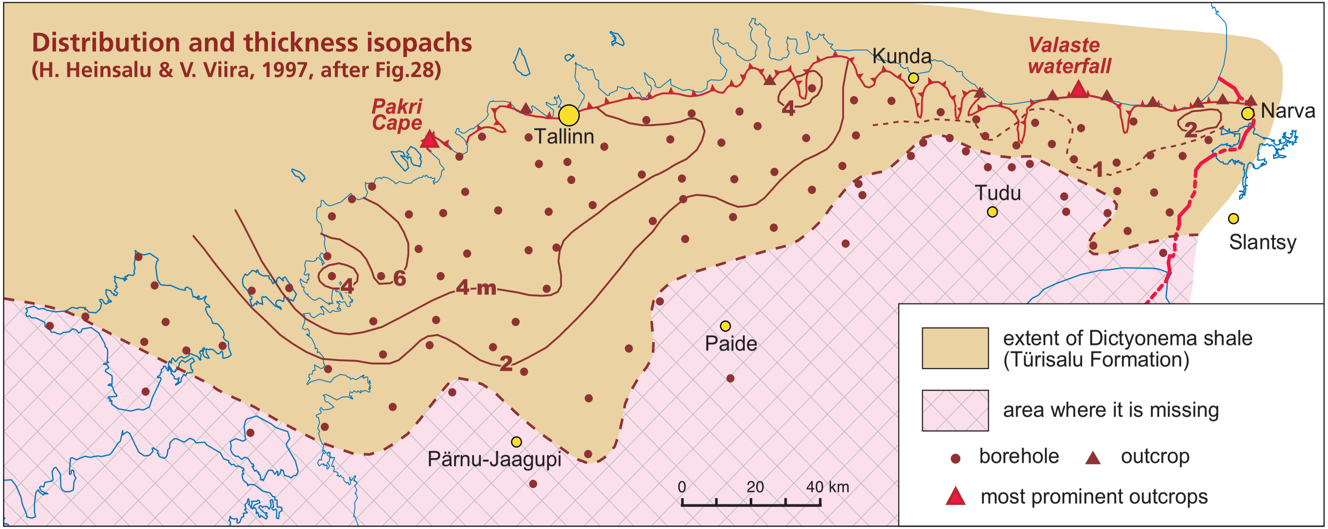
Graptolitic argillite occurs at the foot of the North Estonian Klint in an area extending from the Pakri Peninsula up to the city of Narva. In the geological section, it occurs right on the top of shelly phosphorite formation and is covered by greenish, glauconite-rich clay. The graptolitic argillite is at its thickest (more than 4 m) in western Estonia and its resources are estimated at 60 billion tonnes. Formed in the Early Ordovician marine basin some 480 million years ago, it is much older than kukersite. Owing to the lack of organic matter, the calorific value of graptolitic argillite is rather low (1,500 to 1,600 kcal/kg) and, therefore, it has not yet been used for fuel. However, it contains several rare elements, among them molybdenum, vanadium, and uranium. From 1949 to 1952, graptolitic argillite was mined at Sillamäe for the production of uranium. The mine occupied 24 km^2 and was 15 m deep; the minable layer was a metre thick. Of some 250,000 tonnes of ore brought out of the ground, more than 60 tonnes of uranium compounds were produced. Owing to the very small yield and primitive technology, the production of uranium from local alum shale was found to be inefficient and the plant switched to processing imported raw materials. As a matter of fact, Dictyonema argillite has done more harm than good to people. In the phosphorite quarry at Maardu, which is no longer operating, Dictyonema argillite was removed and deposited in waste dumps; it was an overburden on the phosphorite bed. As a result of its self-ignition, substances harmful to the health of people reached the groundwater. This was one more reason to end the mining of phosphorite in Estonia.

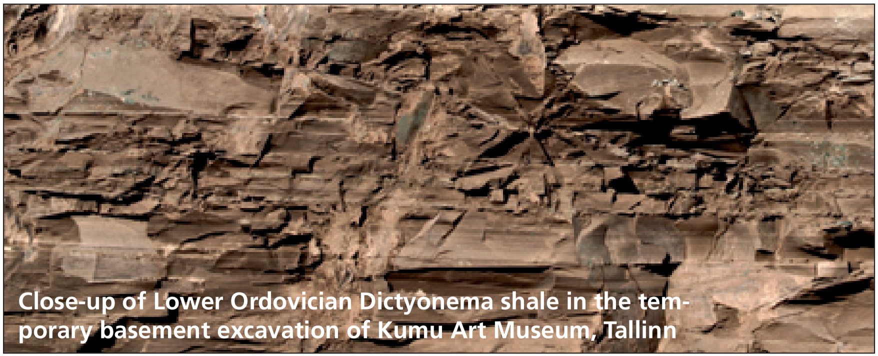
Oil shale or kukersite

To distinguish Estonian oil shale from the other kinds of oil shale in the world, Estonian oil shale is called *kukersite.* The name was derived from the word ***Kuckers***, the German name for Kukruse manor. The Russian palaeobotanist Mihhail Zalesski is acknowledged as the "godfather" of kukersite. During the last century, oil shale was the most important mineral resource of Estonia. It still is today.

What does oil shale consist of?

The quality of oil shale is determined by the organic matter it contains. Besides organic matter, oil shale contains a non-combustible mineral part comprised of terrigenous and calcareous material.

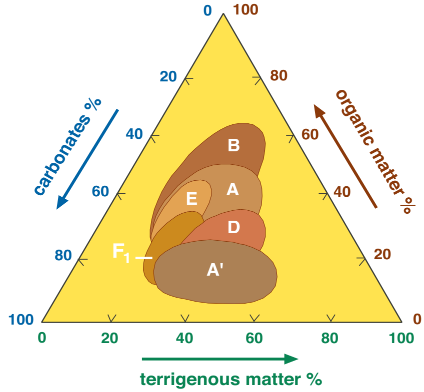



Close-up of Lower Ordovician Dictyonema shale in the temporary basement excavation of Kumu Art Museum, Tallinn


graptolite *Rhabdinopora* sp. *Photo from Inst. Geol. at TUT imagebank*

The amount of organic matter (kerogen) varies greatly by layer and area. It may fluctuate between 15 and 55%. The organic matter of oil shale is characterized by its element composition. The combustible components are carbon (C) and hydrogen (H). The organic matter also includes oxygen and nitrogen and, to a lesser extent, phosphorus, chlorine, and several other elements. An important indicator of organic matter is the ratio H/C. The higher this ratio, the higher the oil content of the oil shale. The H/C ratio of kukersite is 1.51. There are oil shales with even more oil in it, as for example in torbanite (H/C 1.74), in tasmanite (1.55), and in the oil shales from the Green River deposit in the United States (1.53). The oil yield does not depend on the H/C ratio only. It is also controlled by the initial material of the organic matter and the degree of decomposition. Oil yield is expressed in percentages with respect to kerogen. For kukersite, it is 65 to 67%, or about 19 to 23% when recalculated on the rock. According to this value, the Estonian kukersite ranks second after the torbanites of Australia, whose oil yield is about 30%.

The mineral part of oil shales may consist of terrigenous material, carbonates, or



Triangular plot of main constituents in kukersite oil shale, Estonia deposit (H. Bauert ja V. Kattai, 1997, after Fig. 212)

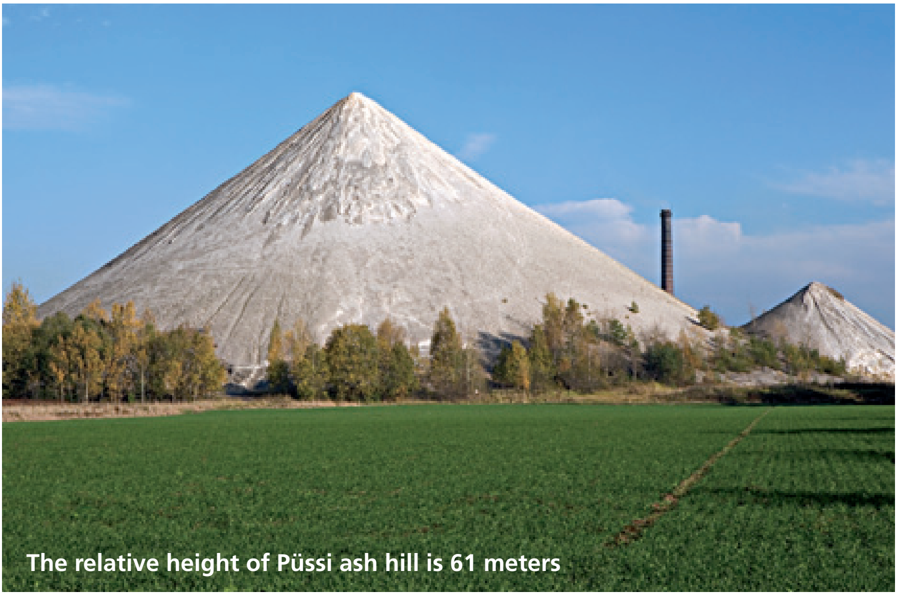
both. The terrigenous material (i.e., mineral grains carried into the sedimentary basin from land) is mainly composed of clay, supplemented by quartz and feldspars. Carbonates are represented by calcium carbonate (calcite) and sometimes dolomite.

Estonian kukersite has a terrigenous and carbonaceous composition. The mineral part usually reduces the calorific value of the oil shale. If the calorific value of the kerogen separated from kukersite reaches 8,900 kcal/kg, then the mean calorific value of the oil shale in the

Cartoon illustrating kukersite organic matter vs ash and moisture content

deposit in Estonia is 3,600 kcal/kg. On combustion, the mineral constituents – mostly carbonates – disintegrate. Thus, as a result of oil-shale combustion, we obtain heat but also many residual or ballast substances. In a thousand tonnes of oil shale, the combustible part forms 350 tonnes and water 100; 550 tonnes remain as ash. In the case of mineral coal, these values are 850, 50, and 100 tonnes, respectively. Hence, oil shale is a low-grade fuel.

The environmental problems arising from oil-shale production are also related to oil-shale composition and geological conditions. After mining and benefi-ciation, much limestone remains unused and is deposited in waste dumps. Oil-shale waste and waste heaps may be considered a rather innocent production residue; however, from time to time they are subject to self-ignition. On the combustion of enriched oil shale, there remains ash, which also has to be deposited. The most toxic waste comes from the oil-shale chemical industry. In north-western Estonia, oil-shale mines cover 450 km^2, which forms 15% of the county's area or 1% of Estonia's territory. The electrical power stations using oil shale emit much carbon dioxide and other gases; the groundwater regime, and often also the water quality, are altered in mined-out areas. Thus, the production and consumption of oil shale change the environment. With the development of the oil shale industry, more attention has to be paid to its effects.

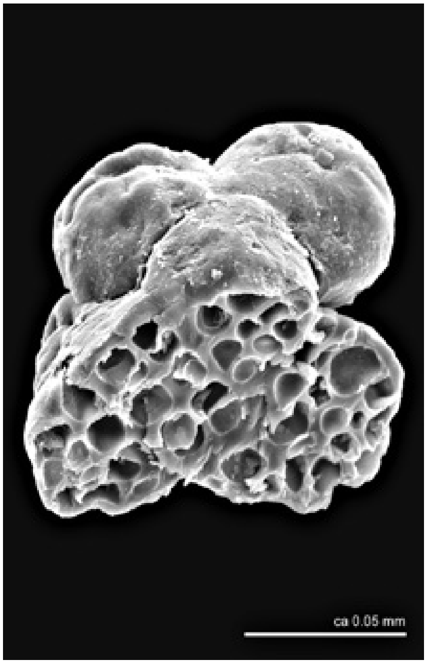


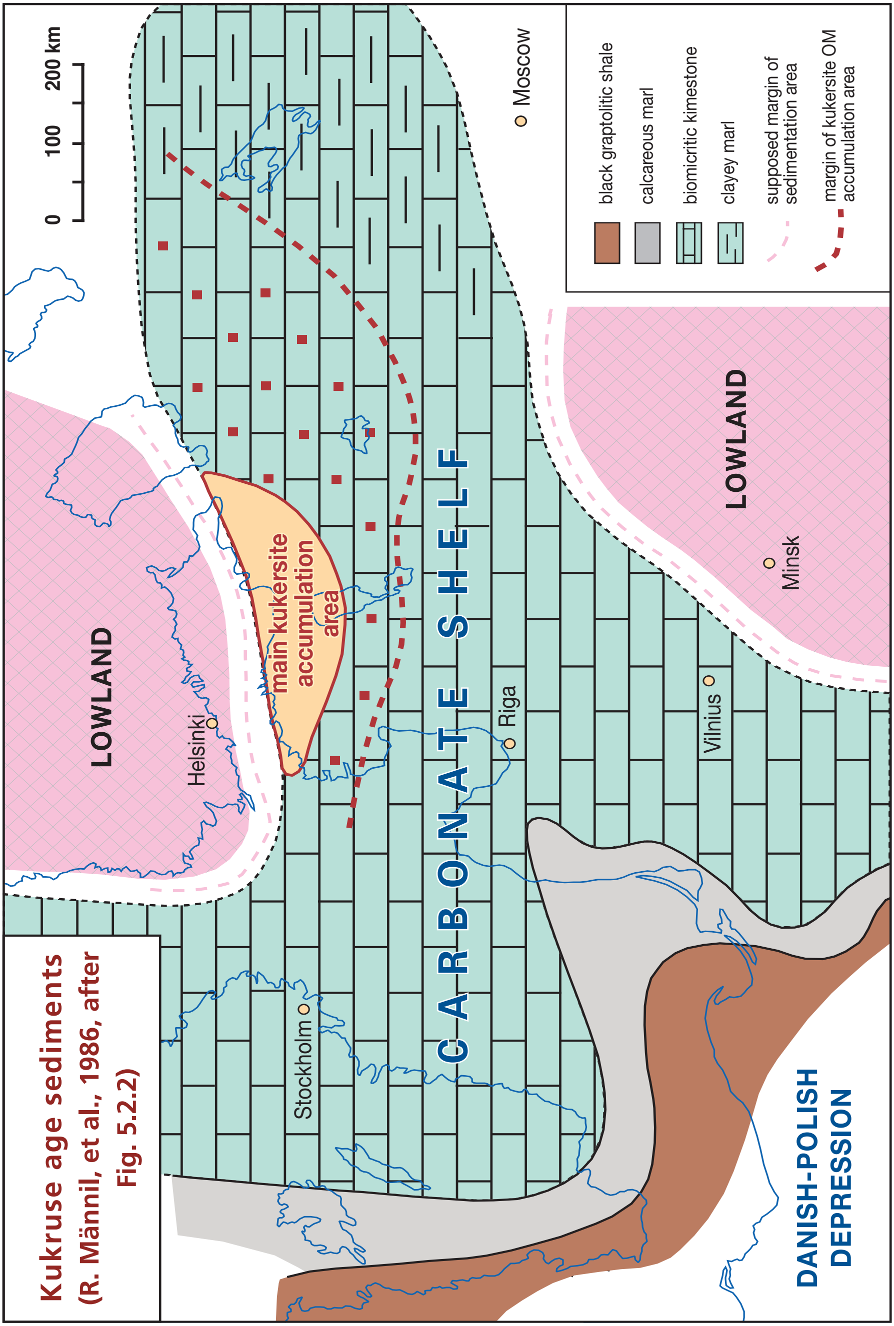
The relative height of Püssi ash hill is 61 meters

How did kukersite oil shale form?

Large-scale production and the ever-growing consumption of oil shale led to an urgent need for scientific studies. In the first decade after the II World War, several Soviet institutions had mining problems. In Estonia, the relevant studies were carried out only in the mining department of the Tallinn Polytechnic Institute (now Tallinn University of Technology). In the beginning of the 1950s, the activities of local Estonian research institutions and researchers rose to the fore. The amount of information related to geology, mining technology, and the oil-shale chemical industry increased. Much factual and assessment material on oil shale accumulated, but detailed theoretical studies were practically absent. Despite the efforts of geologists and oil-shale chemists, the problems related to the formation of kukersite have not yet been unambiguously resolved. The main question is the origin of the organic matter, its decomposition degree, and the conditions of sedimentation. Most investigators agree that marine algae were the initial source of the organic matter in the oil shale. In the Ordovician, only algae thrived everywhere in water basins, as at that time there were no higher plants. They played an important role in providing the Earth's atmosphere with oxygen and creating a favourable environment for other organisms. Opinions differ about the further alteration of algae, the initial material of kerogen. Geologists maintain that the algal structures occur in the kukersite oil shale in an unchanged state or that they have undergone only small changes. This opinion is based on the idea expressed in 1917 by Zalesski. Zalesski studied kukersite under a microscope and concluded that kukersite was formed by micro-organisms now extinct. Because

Cellular structure of *Gloeocapsamorpha prisca* Zalessky, 1917 colony. *SEM image by J. Nõlvak*



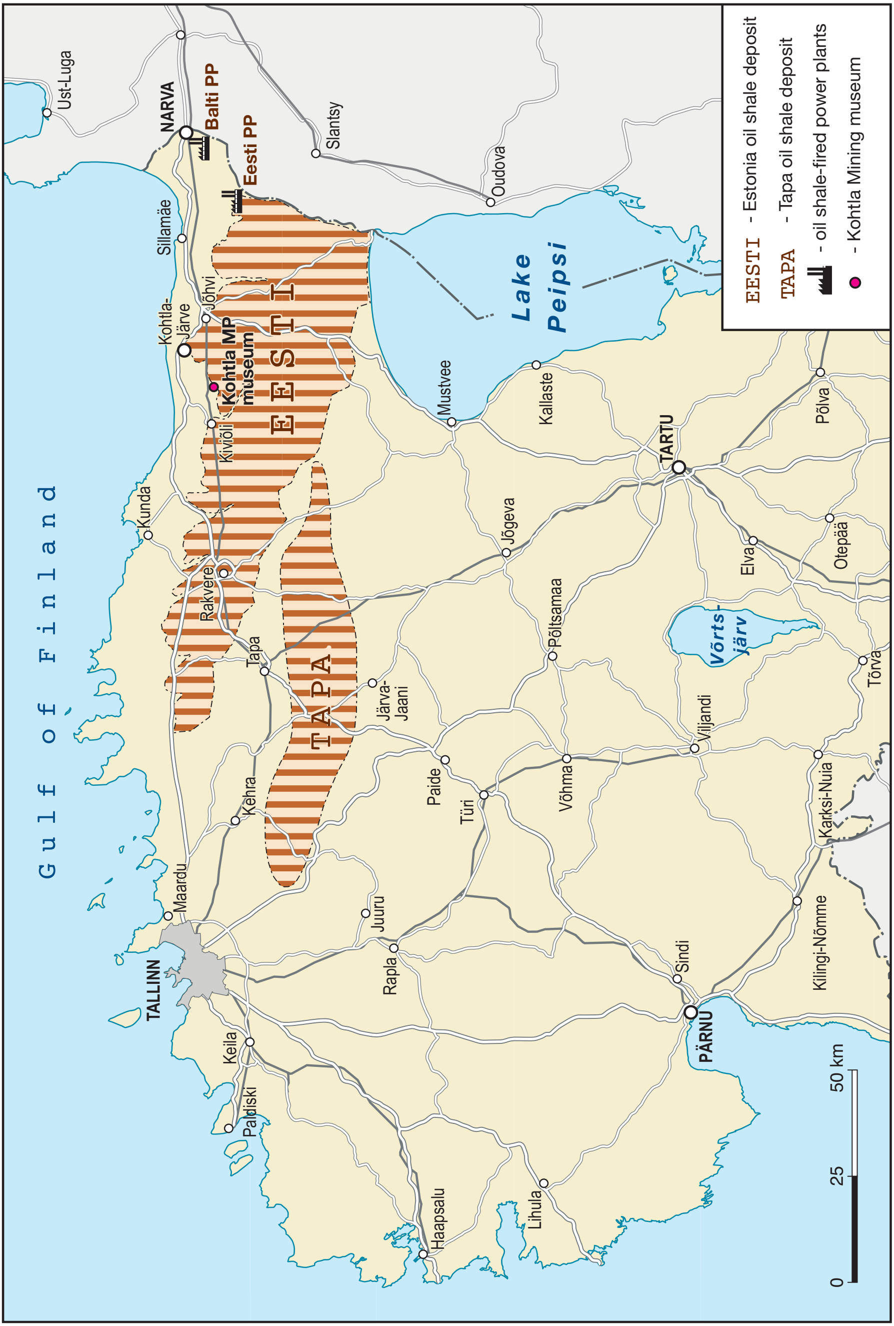


Kukruse age sediments (R. Männil, et al., 1986, after Fig. 5.2.2)

of its similarity to the present day planktonic alga *Gloeocapsa*, the kukersite alga was named *Gloeocapsamorpha prisca*. This idea has withstood the test of time because the kukersite kerogen is very difficult to investigate; it does not dissolve (or it dissolves only in very small amounts in most organic solutions). In the 1950s, oil-shale chemists criticized Zalesski's ideas. They maintained that the initial organic material of kukersite had changed greatly through time; that the structural elements of algae are impossible to recognize; and that, in all likelihood, kukersite had been formed from the remains of representatives of all the marine plants and animals existing then. On their decomposition, new high-molecular colloidal compounds were formed whose lumps recall algal structures only superficially. Later kerogen studies under an electron microscope (SEM) have confirmed M. Zalesski's ideas rather than refuted them. In the studies of the last decade, chemists have also returned to algal structures. Kukersite is believed to have been deposited in shallow coastal waters where algae might have formed extensive mats. Along with the organic matter, calcareous material and clay particles accumulated (they reached the sea from land). When assessing the depth of the sedimentary basin, one has to bear in mind that algae can live only at depths reachable by sunlight.

The extent of oil shale in Estonia

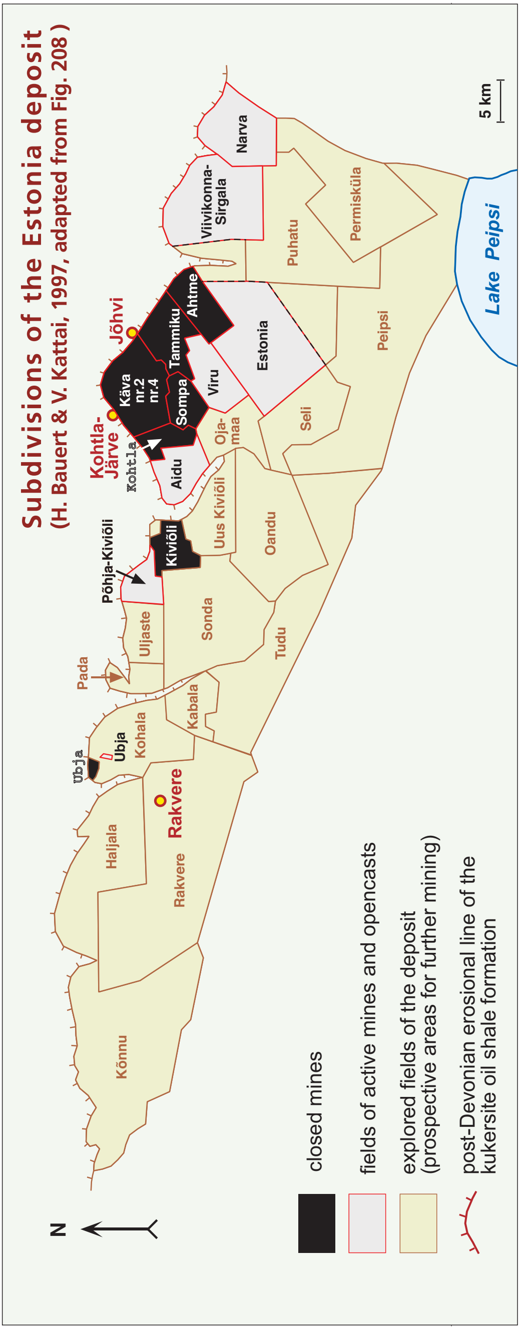
Estonian oil shale, kukersite, formed at the end of the Middle Ordovician and in the beginning of the Late Ordovician. It is, therefore, some 20 million years younger than graptolitic argillite. Kukersite forms thinner or thicker horizontal beds between grey limestone and is well traceable because of its light brown colour. Stratigraphically, kukersite occurs within the Uhaku and Kukruse stages, where up to 50 layers with varying thicknesses have been counted. The seams that are mined in north-western Estonia occur in the lower part of the Kukruse Stage. The oil-shale seams are thickest in the area between the cities of Rakvere and Narva (Estonia deposit) and continue behind the Narva River and Lake Peipsi into the Leningrad District (Leningrad deposit). Oil-shale mining was started in the area where its seams were thickest and where the interbedding limestone layers were not thick enough to hamper mining. The individual kukersite seams (but already too thin to be productive and with considerably lowered organic matter content) can be traced westwards even in the area west of Tallinn. Eastwards, these seams extend several dozen kilometres, from Narva to St. Petersburg. In the south, they are traceable up to the Juuru–Järva-Jaani–Mustvee line. A few kerogen grains have been found in


Gulf of Finland
Lake Peipsi
Võrts-järv
EESTI
TAPA
NARVA
Balti PP
Eesti PP
Ust-Luga
Slantsy
Oudova
Sillamäe
Kohtla-Järve
Jõhvi
Kohtla MP museum
Kiviõli
Kunda
Rakvere
Tapa
Järva-Jaani
Kehra
Maardu
TALLINN
Keila
Paldiski
Haapsalu
Lihula
Rapla
Juuru
Paide
Türi
Võhma
Põltsamaa
Jõgeva
Mustvee
Kallaste
TARTU
Põlva
Elva
Otepää
Tõrva
Viljandi
Karksi-Nuia
Kilingi-Nõmme
Sindi
PÄRNU
EESTI - Estonia oil shale deposit
TAPA - Tapa oil shale deposit
- oil shale-fired power plants
- Kohtla Mining museum
0
25
50 km

drilling cores in contemporaneous limestones (Upper Ordovician Kukruse Stage) in a vast area extending from Gotska Sandön Island in Sweden as far as the eastern boundary of Novgorod District. Southwards, kerogen addition has been noticed in the cored rocks in the vicinity of Lake Võrtsjärv.

Besides the north-eastern mining region, there is another oil-shale deposit in Estonia: the Tapa deposit between Väike-Maarja and Ambla. This area, of east-west orientation, measures 80 km in length and is 10 to 20 km wide. The Tapa beds do not serve as the continuation to those of the Estonia deposit. In the geological section, they are located 5 to 8 m higher and formed later in time. Within the Tapa deposit, one can count several oil-shale seams in the upper part of the Kukruse Stage, separated by relatively thick argillaceous limestone beds which may contain little kerogen addition. In the Tapa deposit, only one oil-shale seam with a thickness of 1.5 to 2.3 m (the co-called III seam) is of commercial significance. Because of the great bedding depth (60 to 170 m below the surface) its mining is not considered feasible.

Aerial view to the mining area at the southern edge of Aidu opencast



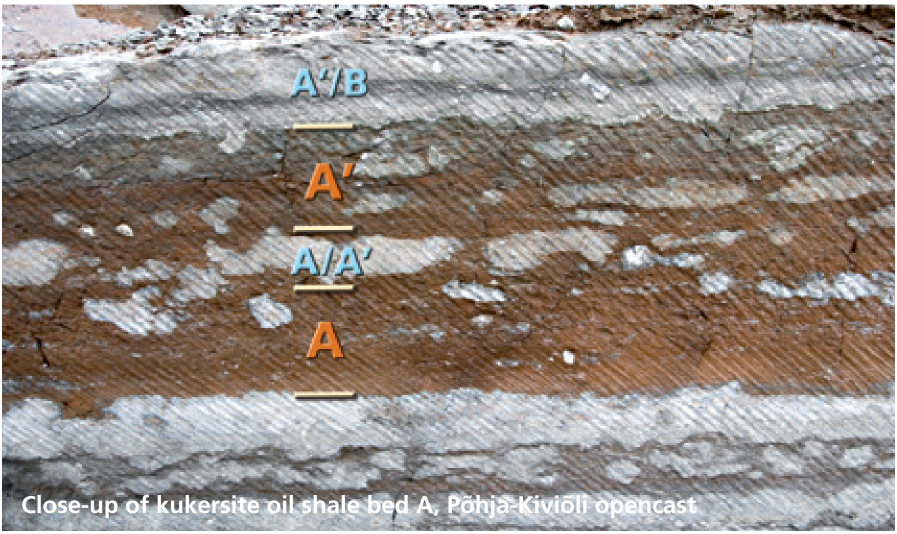
Subdivisions of the Estonia deposit
(H. Bauert & V. Kattai, 1997, adapted from Fig. 208)

Estonia mine

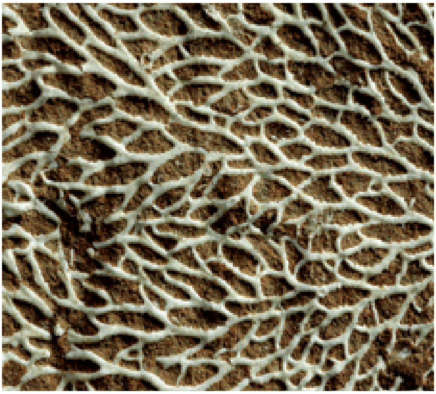
The main oil shale seams in the Estonia deposit

Oil shale has proved to be minable only in the lower part of the Kukruse Stage in north-eastern Estonia (the Estonia deposit) and in the same seams near the city of Slantsy in the Leningrad District of Russia (the Leningrad deposit). The productive complex is formed by seven kukersite seams (marked with letters A to F_2 from down upwards) and six limestone interlayers. The thickness of the productive bed is 2.5 to 3 m, of which oil shale forms 1.8 to 2.6 m and limestone 0.6 to 0.7 m. In the northern part of the deposit, the kukersite seams are close to the ground, and oil shale can be mined in opencasts and shallow mines. Southwards the oil-shale seams descend lower (about 3.5 m per kilometre); it is caused by the general southward dip of the Estonian bedrock. Thus, in the Estonia mine, some 20 km south of the town of Jõhvi, the productive seam of kukersite is at a depth of 70 m already.

Both the oil-shale seams and the interbedding limestone layers differ in thickness, inner structure, and composition. In the lowermost A seam, the oil shale is more argillaceous and up to 20 cm thick. From the next A' seam it is separated by a discontinuous limestone layer (A/A') 3 to 4 cm thick consisting of lens-shaped nodules. A' seam is of thin (6 to 7 cm) argillaceous kukersite. A' and B seams are isolated from each other by bluish-grey argillaceous limestone 15 to 18 cm thick. The miners call it "blue limestone" (A'/B). B is the thickest oil-



Close-up of kukersite oil shale bed A, Põhja-Kiviõli opencast

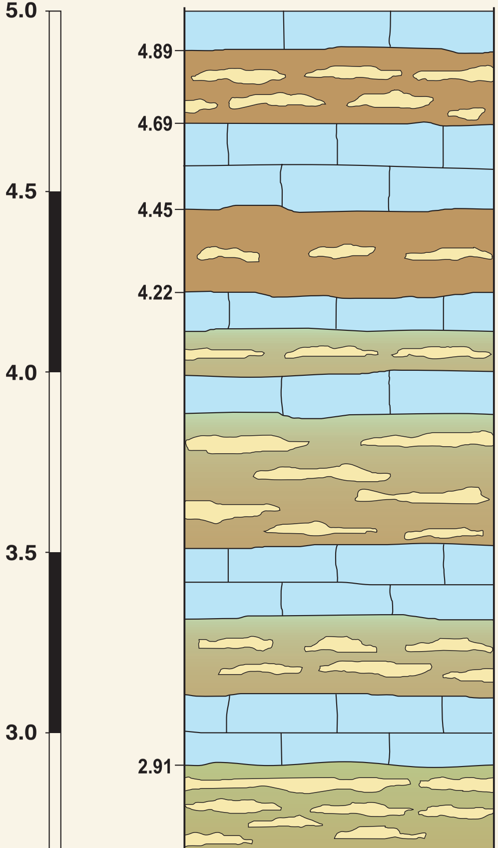


Fossils from Kukruse age:
- fragile, branched bryozoa (upper left)
- inner view of brachiopod valve (up)
- ichnofossils filled up carbonate mud are charactericstic to the upper part of kukersite bed C (left)
- large trilobite on kukersite oil shale surface (below)

Photos from Inst. Geology at Tallinn University of Technology imagebank

PÕHJA - KIVIÕLI OIL SHALE OPENCAST

geological cross-section



bed indeks	bed thickness m	calorific value* kcal/kg MJ/kg	oil yield %
H	0.20	1950/8.2	14.6
G/H	0.24		
G	0.23	3770/15.8	28.1
F_2/G	1.31		
F_2	0.29	1220/5.1	9.1

oil shale bed sequences

G – H
0.67
1540/6.4
11.4

kukersite oil shale

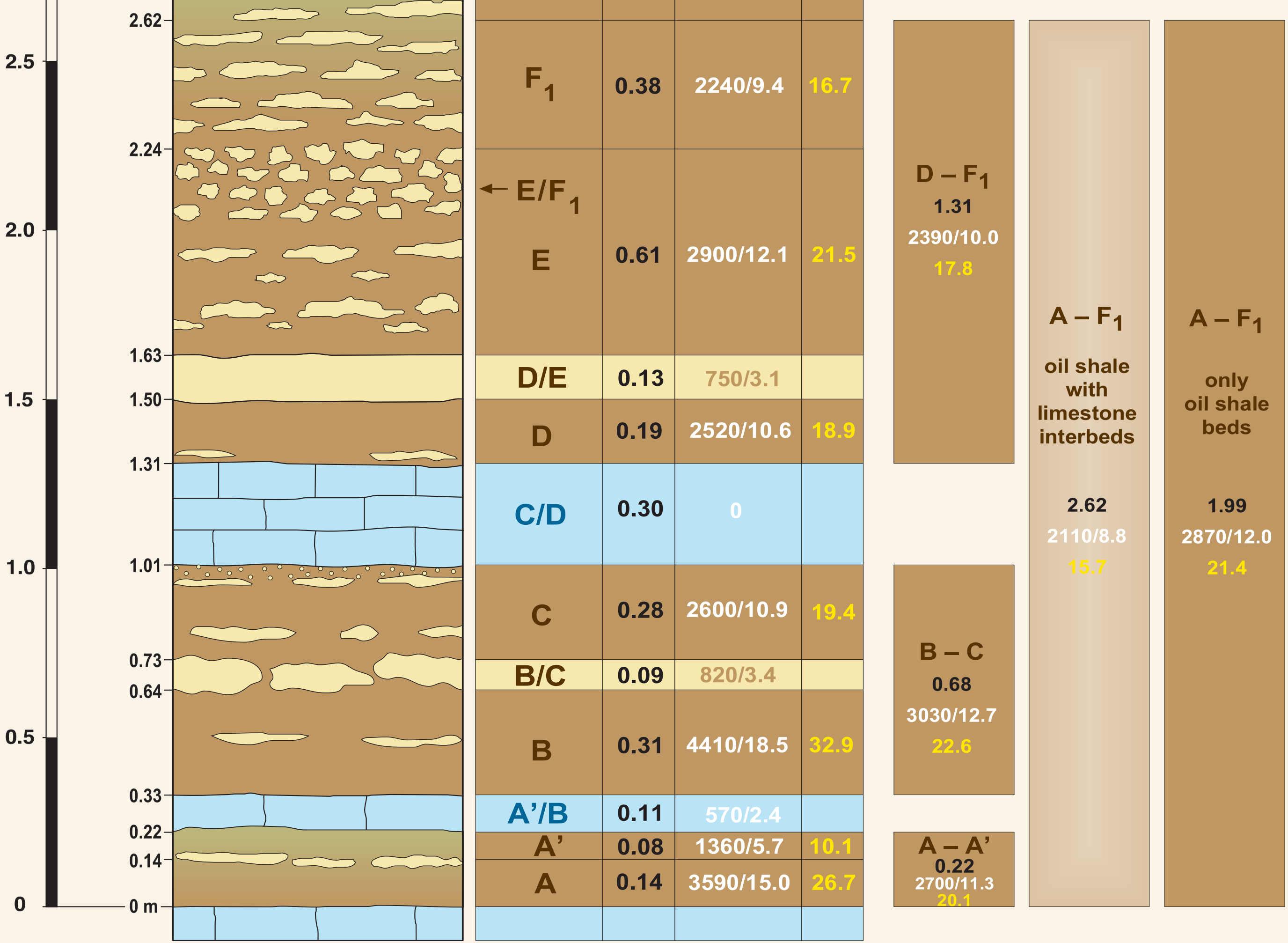
oil shale, very clayey

limestone

kerogenous limestone

*calorific values are determined by calorimetric bomb method

compiled by Vello Kattai, 2005



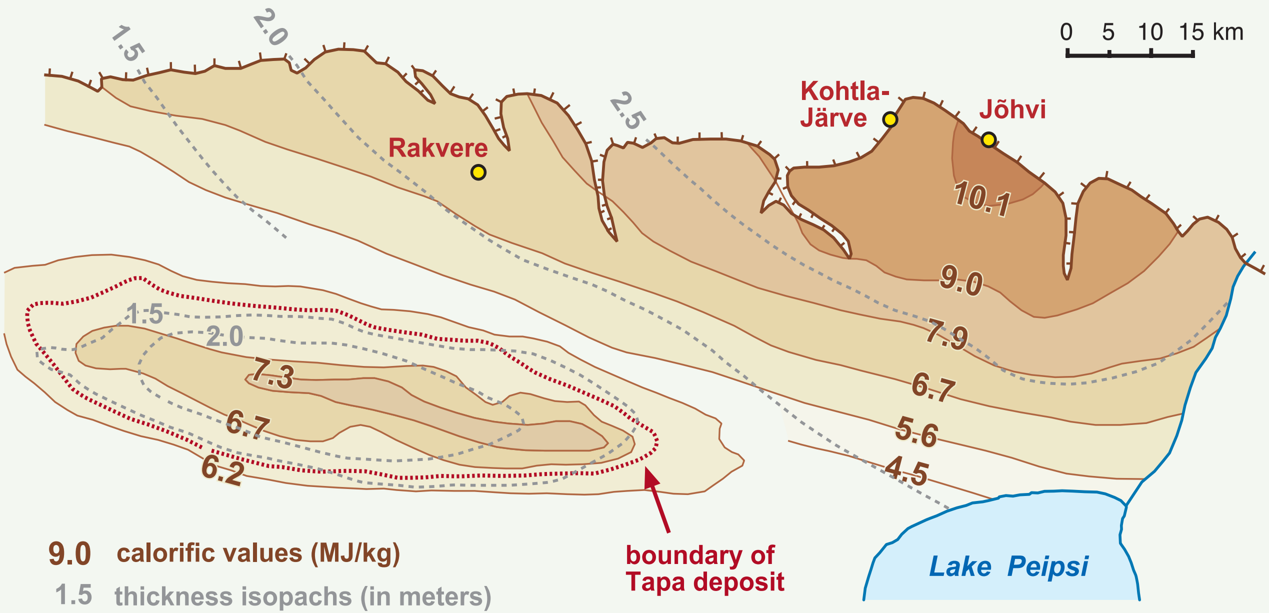
2.5
2.0
1.5
1.0
0.5
0
2.62
2.24
1.63
1.50
1.31
1.01
0.73
0.64
0.33
0.22
0.14
0 m
F1 0.38 2240/9.4 16.7
E/F1
E 0.61 2900/12.1 21.5
D/E 0.13 750/3.1
D 0.19 2520/10.6 18.9
C/D 0.30 0
C 0.28 2600/10.9 19.4
B/C 0.09 820/3.4
B 0.31 4410/18.5 32.9
A'/B 0.11 570/2.4
A' 0.08 1360/5.7 10.1
A 0.14 3590/15.0 26.7
D – F1 1.31 2390/10.0 17.8
B – C 0.68 3030/12.7 22.6
A – A' 0.22 2700/11.3 20.1
A – F1 oil shale with limestone interbeds 2.62 2110/8.8 15.7
A – F1 only oil shale beds 1.99 2870/12.0 21.4

shale seam with the highest kerogen content (up to 50%). In the central part of the deposit, the seam is 0.75 to 0.8 m thick; the thickness decreases uniformly towards the periphery of the deposit. The kukersite of the B seam is chocolate-brown with a very fine lamination and accumulations of fragile white calcareous fossil skeletons on bedding planes. This seam is usually recognized as the typical oil shale of Estonia. The B seam is separated from the overlying C seam by an elongated, nodular-like beige-color limestone (B/C), which is 10 to 12 cm thick. In the C seam, the content of kerogen is somewhat lower than in the B seam, and on two or three levels the seam is penetrated by discontinuous interlayers of limestone lenses. The seam is about 30 cm thick. In the uppermost quarter of the seam there are lots of worm burrows (trace fossils), 0.5 cm in diameter, filled with very light-grey calcareous material, which provides the rock's cross-section with a white-dotted outlook. Miners call this kind of rock "horseskin".

The limestone layer C/D is situated in the middle of the productive seam and divides it into two almost equal halves. The limestone is relatively pure, its thickness is 20 to 25 cm. Frequently, the seam breaks into two equal parts in the middle; from this comes its popular name, "twin-limestone". The seam is easily recognizable and traceable in all mines and boreholes and serves as a good marker level for the whole productive seam. The D seam immediately above the "twin-limestone" is represented by slightly argillaceous oil shale with a thickness up to 20 cm.

The limestone between the D and E seams is beige because of the addition of kerogen. It is hard, its thickness is uneven, it is occasionally interrupted, and it is up to 15 cm thick. Owing to its peculiar colour, it is often called "pink limestone" (D/E). The E seam ranks second in kerogen content (55%) after the B seam in the oil-shale productive bed. In this seam, the content of the limestone nodules is also lower. The thickness of the seam is about 40 cm. It differs from the B seam in its somewhat more reddish shade; also, the debris of fossils is more evenly distributed in the rock. Upwards, three seams without distinct boundaries can be distinguished: E/F_1, F_1, and F_2.

The E/F_1 seam is not a typical limestone interlayer. In it, kukersite and lumps of kerogenic limestone are irregularly intertwined. Limestone nodules are irregular in shape, with angular contours; there are small hollows filled with calcite and pyrite crystals. It is practically impossible to separate limestone lumps and kukersite. Limestone makes up 50% or more of the seam. Owing to the hardness and compactness of the seam, it is called "devil's skin". The boundary with



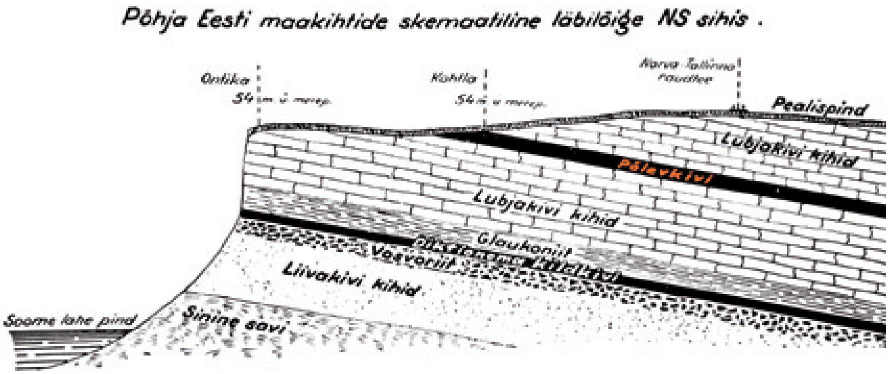
Thickness isopachs and calorific values for minable seams A-F_1 of Estonia deposit and kukersite seam III of Tapa deposit (H. Bauert & V. Kattai, 1997, after Fig. 211) the overlying F_1 seam is transitional and is usually placed on the level where the shape and bedding of limestone lumps become more regular. The oil shale in the F_1 seam is relatively rich in kerogen (about 40%) and there are six or seven horizontal discontinuous limestone interlayers. The thickness of the seam reaches 60 to 70 cm. There is no distinct boundary between the F_1 and F_2 seams. F_2 is considered the uppermost 30 cm of the complex in which the kerogen content steadily decreases. The seam is rich in limestone nodules.

Usually, the limestone with a smooth upper surface under the A seam serves as the floor of the mine. In the case of the thin and argillaceous A seam, the upper surface of the A'/B seam may also be left as the floor, depending on the mining method. Mining is usually carried out down to the F_2 seam, but sometimes it is also subject to production.

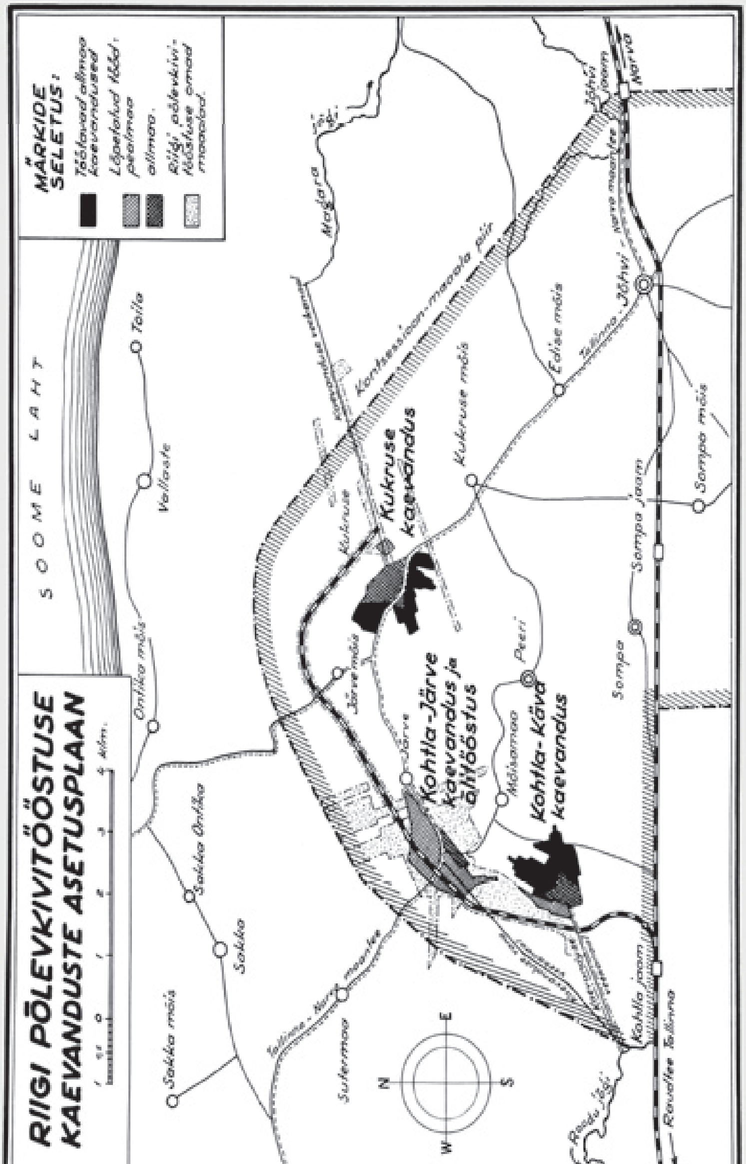
All rocks in the productive bed contain many fossils or their crushed skeletal particles – debris. In the Kukruse Stage, palaeontologists have found some 360 species of fossils (two to three times as much as in other stages). Frequently, the fossils look very attractive. One may find here white, lace-like whitish bryozoans and well-preserved trilobites. Abundant trace fossils are also indicative of favourable living conditions.

The history of oil shale production in Estonia

Generally known stories about the discovery of oil shale tell of a peasant who built a stove from oil shale which burned up along with the firewood and about herder boys who threw into the fire pieces of oil shale which, to their astonishment, caught fire. Oil shale had attracted scientists' attention by the end of the eighteenth century. Since then, there have been periods when oil shale was a matter of topical interest and other periods when it fell into oblivion. Earlier experiments and studies, including those by Georgi (1791) and Helmersen (1839), led to the conclusion that the rocks could be used for producing heat and tar or oil for local needs. During the investigations in the second half of the nineteenth century, it was discovered that the thickest oil-shale beds lay near Kukruse manor. Fr. Schmidt, a founder of Estonian geology, named the part of the geological section, which comprised oil shale, the Kukruse Stage. Thereafter, chemists at Tartu University studied the chemical composition of oil shale and came to the conclusion that its production was not useful because of the small thickness of the seams and its high ash content. The oil shale was forgotten once again. A new wave of interest in oil shale arose in 1910. During World War I, when the city of Leningrad was short of fuel, Nikolai Pogrebov, a Russian geologist, was sent to Estonia to study the potential of oil shale as a fuel. Under his leadership, extraction of oil shale was started in the Kohtla-Järve area, where the thickest oil-shale beds were discovered. In 1916, 22 wagons carrying oil shale were sent to Petrograd. The object was to study the potential of oil shale for producing cement, gas, and locomotive fuel. Since the results proved to be beyond all expectations, the Main Committee of Fuels in Petrograd decided to create an open oil-shale pit near the Pavandu inn and Kohtla railway station with an annual output of up to 35 million poods (570,000 tonnes). At the same time, open pits working on private capital were opened in the villages of Kukruse and Järve. In February 1918, Estonia was occupied by German troops, and work in these first oil-shale enterprises was interrupted. In November 1918, the government of Estonia founded an oil-shale department at the Estonian Ministry of Commerce and Industry and charged it with the organization of the oil-shale industry. Mart Raud, the head of the department, made a great contribution to the foundation and development of the oil-shale industry in Estonia. In the spring of 1919, excavation of oil shale was started again in the Pavandu opencast. The first underground mine was put into operation in 1920. In 1921, an oil-shale laboratory and a small oil plant were opened at Kohtla. The aim was to study retorting methods and attained raw oil. The second half of the 1930s was the heyday of the oil-shale industry. This was mainly due to the shale oil, of which almost half was exported. With its oil shale, Estonia was no longer dependent on fuel



Sketchy north-south geological section of Cambrian-Ordovician deposits in northeastern Estonia (repro from book "A/S Esimene Eesti Põlevkivitööstus, endine Riigi Põlevkivitööstus 1918-1938")


RIIGI PÕLEVKIVITÖÖSTUSE
KAEVANDUSTE ASETUSPLAAN
MÄRKIDE SELETUS:
Töötavad allmaa kaevandused
Lõpetatud tööd: pealmaa
allmaa.
Riigi põlevkivitööstuse omad maaalad.
SOOME LAHT
Kukruse kaevandus
Kohtla-Järve kaevandus ja õlitööstus
Kohtla-Käva kaevandus
Kontsessioon-maaala piir
Tallinna-Narva maantee
Tallinna-Jõhvi-Narva maantee
Ontika mõis
Valaste
Toila
Saka
Saka Ontika
Saka mõis
Järve mõis
Järve
Mõisamaa
Peeri
Kukruse
Kukruse mõis
Edise mõis
Sompa
Sompa jaam
Sompa mõis
Kohtla jaam
Jõhvi jaam
Narva
Raudtee Tallinna
N
S
E
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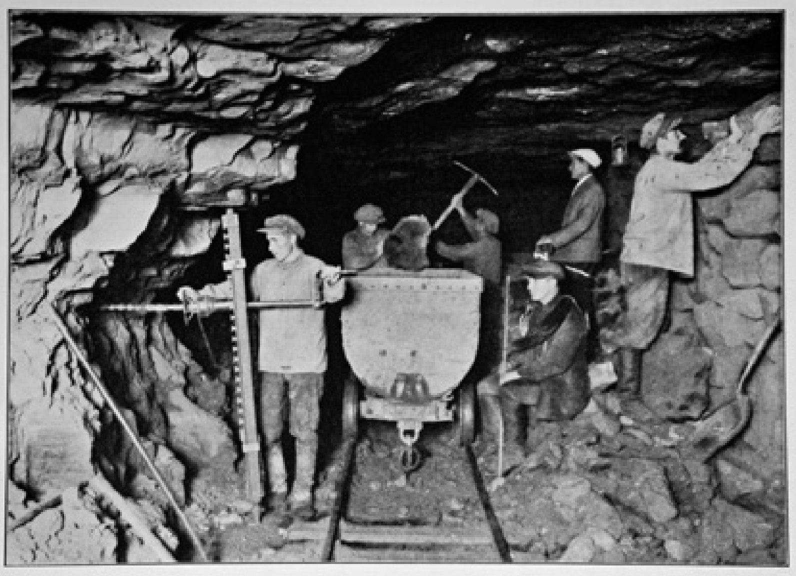
km

from other countries. By the last years of the independent Estonian republic, seven enterprises had invested their capital into the oil-shale industry. One of those – the stock company "The First Estonian Oil-Shale Industry" – worked on the national capital, the other six on foreign private capital. During the years of the Estonian Republic, a bit more than 5 million tonnes of oil shale were mined. Oil shale was the cheapest and most available fuel and its price was stable. The reserves of oil shale were expected to last for 4,000 to 5,000 years. It was the national pride of Estonia, our brown gold.

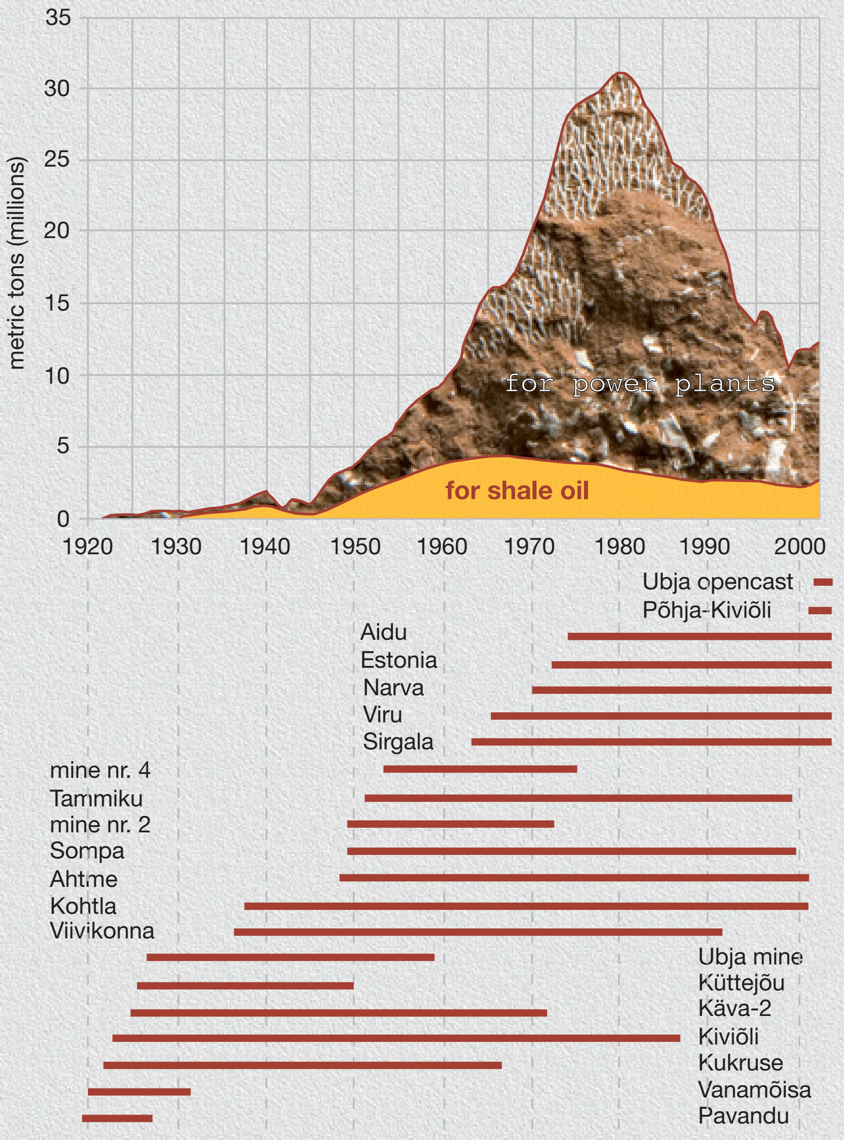
Plan (left) ja photo (below) from a book "Riigi Põlevkivitööstus 1918-1933"

During World War II, Germany showed interest in oil shale as a mineral resource of strategic significance and started founding new oil-shale enterprises in Estonia. In the autumn of 1944, Russian troops invaded Estonia. The retreating German army destroyed the retorting plants at Sillamäe, Kohtla, and Kiviõli; some of the mines were burnt, others inundated. The electrical power stations using oil shale at Püssi and Kohtla-Järve were also disabled.

In the Soviet period, oil-shale production was subordinated to the USSR Coal-mining Ministry. Oil-shale mining on the spot was in the competency of the enterprise "Eesti Põlevkivi". By 1946, six



KUKRUSE ALLMAA-KAEVANDUS. MÄETÖÖLISED.

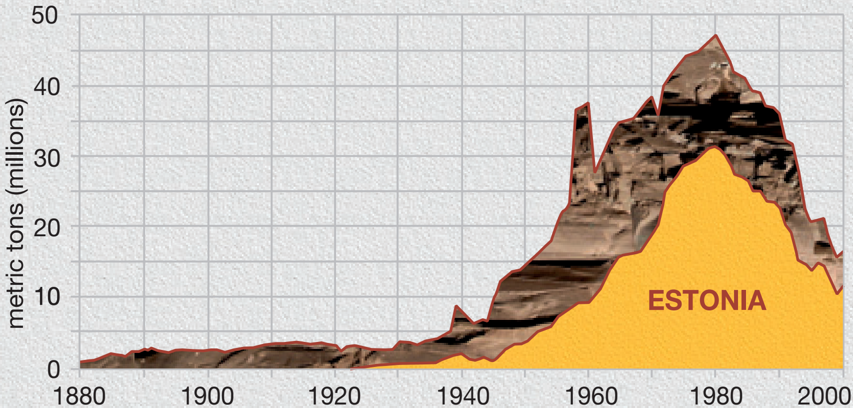


Oil shale mining and utilization in Estonia with bargraphs showing life-span of oil shale mines and opencasts (V. Kattai, 2003, after Fig. 5.4) mines had been restored and the pre-war output regained. The oil-shale industry was developed, first of all, to provide Leningrad and Estonia with household gas. Up to 1960, the main oil-shale consumers were the Kohtla-Järve and Kiviõli shale oil plants and the railway. Fine oil shale was used as a fuel at local electrical power stations. From 1960 to 1970, large electrical power stations using oil shale were launched – Baltic Thermal Power Station in 1965 and Estonian Thermal Power Station in 1973. With this the structure of oil-shale consumption was altered: now 80% of mined oil shale was used for producing energy. At the same time, new mines and more oil shale were urgently needed. Thus, in 1962 an opencast was opened at Sirgala. In 1965 the Viru mine (mine No. 7) got its start. The Narva opencast started to operate in 1970 and the Estonia mine in 1972. At the same time, the mine fields in the centre of the Estonian oil-shale deposit were exhausted. Mining operations shifted inevitably towards the peripheral parts of the deposit, where the minable seam is thinner, its quality lower, and its situation deeper, making excavation more expensive and labour-intensive. Oil-shale production reached its peak in 1980, when 31.3 million tonnes of oil shale were mined and the mined volume exceeded the consumption. Since the launch of the Sosnovyi Bor nuclear power plant, about 50 km east of Narva, less oil shale was needed for producing electricity in the joint electricity distribution system with NW Russia, and the production of oil shale started to drop from year to year; in 1990, it was less than 10 million tonnes, an amount equal to the amount of oil shale produced in 1960. Oil-shale production has stabilized at a level of 13-14 million tonnes per year. The greater part of the produced oil shale is still used as fuel at the electrical power stations. Since the 1960s, Estonia has been the greatest oil-shale producer and consumer in the world. In the 1980s about two-thirds of the world's oil-shale output came from Estonia.

The production of oil shale and its use as a raw material in the oil and chemical industry and power engineering caused serious environmental problems in northeastern Estonia during the early and middle period of the oil-shale industry. Environmental effects and the resulting immediate hazards were greatest in the 1980s. To date, attention is focused on the problems related to the environmental pollution caused by both excavation and further use of oil shale. Much has been done at the electrical power stations at Narva. For example, after installation of new boilers and up-to date purification facilities, the emission of carbon dioxide, nitrogen, and sulphur compounds has been reduced substantially.

Oil shale elsewhere in the world

The world's oil shale reserves are immense. According to the United States Geological Survey, they reach 410 billion tonnes. Oil shale formations are known throughout the whole Phanerozoic, and its deposits have been recorded from more than 600 places in 30 countries. The largest reserves are in the United States. Since oil shale is of local importance, it has local names. The oil shale studied in more detail include the Green River deposit in the United States, torbanite in Australia, alum shale in Sweden, kukersite in Estonia, and the oil shale of Jordan. Estonia is currently the greatest producer of oil shale in the world. Oil shale is also mined in Russia, Australia, China, and Brazil (in the latter three countries only for oil production). Oil shale is not excavated in France, Scotland, Canada and several other states anymore. They prefer to use crude oil, which is much cheaper. However, the shale-oil output is marginal compared to crude oil, the daily worldwide production of which is 75 million barrels. The development of the oil-shale industry in the world is immediately controlled by the price of crude oil. In the United States, shale oil is considered one of the possible alternatives to oil, but not until the remote future. In Estonia, green power and also nuclear power have been suggested as alternatives.



Oil shale production in Estonia and rest of the World between 1880-2000 (J. Dyni, 2003, adapted after Fig. 18)

Oil shale mining in the Põhja-Kiviõli opencast: mining of D-F_1 oil shale sequence (above). Surface miner Wirtgen 2500 SM allows selective mining of oil shale seams B+C as well as a pure limestone interbed C/D (below)

Where to learn more about kukersite oil shale and oil-shale mining?

The Kohtla-Järve oil-shale museum and Kohtla Mining museum provide an opportunity to learn about the history of the mining and consumption of oil shale in Estonia. The Kohtla Mining museum is in the former Kohtla mine at Kohtla-Nõmme. The museum was opened in 2001. Under the guidance of former miners, it is possible to descend into an old mine to a depth of 8 m, see the oil-shale section and operational underground mining equipment, drive on a workers' train, and have a miner's meal. The mining museum is an attraction to visitors, because everyone wishes to be underground at least once during his lifetime.

Use of former Russian drilling equipment demonstrated in Kohtla Mining museum. Photo by E. Käiss

Mining at the Vanaküla opencast near Kohtla Mining museum

SÕNASELETUSI

Alum shale (in Scandinavia) – Middle Cambrian to Lower Ordovician sedimentary rock rich in organic matter and pyrite, which accumulated under generally low oxygen concentrations

Argillite – prevailingly microlaminated sedimentary rock formed as a result of the consolidation of clay, breaks into thin plates

Barrel – a unit of liquid capacity or volume in the USA and Great Britain. In the USA a barrel of oil is equal to 42 gallons (= 159 liters)

Brachiopod – marine animal with bivalve shell having a pair of arms bearing tentacles for capturing food

Bryozoa – sessile marine animal found in branching colonies in kukersite oil shale

Calorific value – amount of heat generated by a given mass (solid and liquid fuels) or volume (gaseous fuels) of fuel when it is completely burned. In practice, it is often measured in kilocalories (1 kcal = 4.1868 kJ)

Cyanobacteria – a photosynthetic bacteria, generally blue-green in color and in some species capable of nitrogen fixation. Cyanobacteria were once thought to be algae. Also called *blue-green alga*

Detritus – crushed skeletal remains of dead organisms floating in water or deposited on the bottom of water basins

Dictyonema – a genus of graptolites wide spread in Palaeozoic seas

Dictyonema shale – a term used up to the present to denote a certain kind of oil shale in Estonia (see also graptolitic argillite)

Dolomite – both a carbonate rock and mineral $CaMg(CO_3)_2$ consisting of calcium-magnesium carbonate

Fossil – the remains of a once-living organisms, preserved in the rocks

Georgi, Johann Gottlieb (Ivan Ivanovitch) 31.12.1729 – 27.10.1802 – a Russian explorer of German origin, naturalist and ethnographer, academician of St. Petersburg Academy of Sciences (1783). Undertook longer expeditions in Russia, his works also comprise information about Estonia and the Estonians

Glauconite – A greenish mineral of the mica group, a hydrous silicate of potassium, iron, aluminum, or magnesium, $(K,Na)(Al,Fe,Mg)_2(Al,Si)_4O_{10}(OH)_2$, found in greensand and used as a fertilizer and water softener

Graptolite – an extinct colonial marine animal with a planktonic way of life. Common in Palaeozoic seas

Graptolitic argillite – earlier known as Dictyonema shale. An Early Ordovician blackish brown argillaceous rock rich in organic matter and often with graptolite fossils (corresponds to the Türisalu Formation in Estonia)

Helmersen, Gregor von 11.10.1803 – 15.02.1885 – Russian geologist of German origin born in Estonia, academician of St. Petersburg Academy of Sciences (1850). Founder of the national Geological Survey in Russia, supervisor of geological mapping. In his works he also deals among others with Estonian erratic boulders and oil shale finds

Kerogene – insoluble part of organic matter in oil shales

Kukersite – Estonian oil shale, derived its name from **"*Kuckers*"**, which is the German name for the Kukruse manor located in NE Estonia

Ordovician – the second period of the Palaeozoic era preceded by the Cambrian and followed by the Silurian. Started ca 490 million years ago and lasted 45 million years. The period is subdivided into the Early, Middle and Late Ordovician

Plankton – the collection of tiny plants and animals floating freely in water; phytoplankton – plants, zooplankton – animals

Pogrebov, Nikolai Fjodorovitch 17.11.1860 – 10.01.1942 – Russian hydrogeologist. In 1916 he studied the geology of Estonian oil shale and its production possibilities, published a series of papers on this subject in 1916-1923

Pood – an old Russian unit of weight equivalent to 16.38 kg

Pyrite – a brass-colored mineral, FeS2, common in Estonian sedimentary rocks

Raud, Märt 23.07.1878 – 04.03.1952 (according to other data the date and place of death not known) – engineer, founder and developer of Estonian oil shale industry in 1918—1940, chairman of the company The First Estonian Oil Shale Industry

Retorting – dry distillation, heating to a high temperature in an airless condition

Schmidt, Carl Friedrich 27.01.1832 – 21.11.1908 – Baltic German geologist and botanist born in Estonia, academician of St. Petersburg Academy of Sciences (1885). His main papers deal with the stratigraphy and fauna of Lower Palaeozoic rocks in Estonia and neighboring areas. Acknowledged as the founder of Estonian geology

Series – a subdivision of a system, rocks formed during a relevant time priod, the name of the series is mostly formed by placing an adverb (Lower, Middle, Upper) in front of the name of a corresponding system

Stage – a subdivision in the classification of stratified rocks formed at the same age in a certain region; the name of the stage is derived from the name of the locality where it occurs in its typical form

Stratigraphy – branch of geology studying the age succession of rocks and their relations in space

Tasmanite – oil shale from the Island of Tasmania

Terrigenous –originating from land, of land origin

Torbanite – named after Torbane Hill in Scotland, is a black oil shale whose organic matter is telalginite derived from lipid-rich *Botryococcus* and related algal forms

Trilobite – an extinct arthropod that was abundant in Paleozoic times; had an exoskeleton divided into three parts

Zalesski, Mihhail Dmitrievitch 15.09.1877- 22.12.1946 – Russian palaeobotanist, investigator of plant remains in coals and oil shale. The founder of algal structures in kukersite kerogene

IUGS ICS Geological Time Scale 2004 (www. stratigraphy.org)

adapted and modified by Estonian Commission on Stratigraphy (www.gi.ee/ESK/)

EON	ERA	SYSTEM	SERIES	AGE (Ma)
				0,00
Phanerozoic	**Cenozoic**	QUATERNARY	Holocene	0,0115
			Pleistocene	1,806
		NEOGENE	Pliocene	5,332
			Miocene	23,03
		PALEOGENE	Oligocene	33,9 ± 0,1
			Eocene	55,8 ± 0,2
			Paleocene	65,5 ± 0,3
	Mesozoic	CRETACEOUS	Upper Cretaceous	99,6 ± 0,9
			Lower Cretaceous	145,5 ± 4,0
		JURASSIC	Upper Jurassic	161,2 ± 4,0
			Middle Jurassic	175,6 ± 2,0
			Lower Jurassic	199,6 ± 0,6
		TRIASSIC	Upper Triassic	228,0 ± 2,0
			Middle Triassic	245,0 ± 1,5
			Lower Triassic	251,0 ± 0,4
	Paleozoic	PERMIAN	Lopingian	260,4 ± 0,7
			Guadalupian	270,6 ± 0,7
			Cisuralian	299,0 ± 0,8
		CARBONIFEROUS	Pennsylvanian	318,1 ± 1,3
			Mississipian	359,2 ± 2,5
		DEVONIAN	Upper Devonian	385,3 ± 2,6
			Middle Devonian	397,5 ± 2,7
			Lower Devonian	416,0 ± 2,8
		SILURIAN	Přidoli	418,7 ± 2,7
			Ludlow	422,9 ± 2,5
			Wenlock	428,2 ± 2,3
			Llandovery	443,7 ± 1,5
		ORDOVICIAN	Upper Ordovician	460,9 ± 1,6
			Middle Ordovician	471,8 ± 1,6
			Lower Ordovician	488,3±1,7
		CAMBRIAN	Furongian	501,0±2,0
			Middle Cambrian	513,0±2,0
			Lower Cambrian	542,0±1,0
Proterozoic	**Neoproterozoic**	EDIACARAN		630
		CRYOGENIAN		850
		TONIAN		1000
	Mesoproterozoic	STENIAN		1200
		ECTASIAN		1400
		CALYMMIAN		1600
	Paleoproterozoic	STATHERIAN		1800
		OROSIRIAN		2050
		RHYACIAN		2300
		SIDERIAN		2500
Archean	**Neoarchean**			2800
	Mesoarchean			3200
	Paleoarchean			3600
	Eoarchean			~4500

ISBN 978-9985-9834-2-3