# Narva Longwall Mining Project

Narva open cast mine is situated in the north-east part of Estonia and is located in Illuka, Vaivara and Toila parish, Ida-Virumaa county, Estonia.

Narva open cast is over 18 km wide and 8 km long. The mining face extends for over 27 km.

Narva's mining license covers a total combined area of 163 km$^2$.


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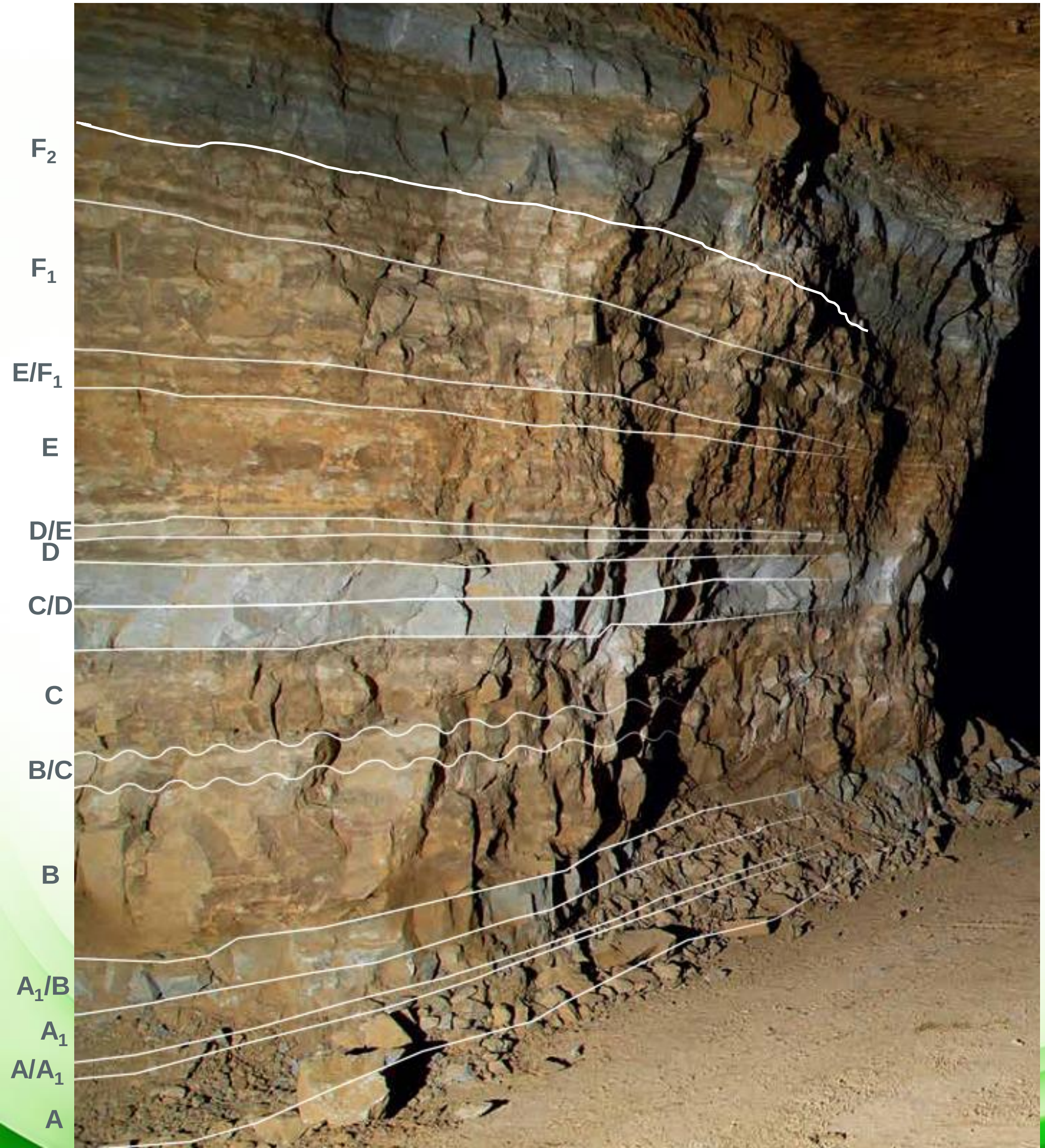
# Estonian oil shale




Oil shale is a sedimentary rock formed on the bottom of lakes and seas ca 450 million years ago. Oil shale is made from the organic substances like primitive single-cell organisms, bacteria, phyto- and zooplankton and algae that were the biomass of ancient lakes and seas.

Oil shale layer compressive strength is 20–40 MPa and limestone layer is 40–90 MPa.

Volume density is 1.5–1.8 and 2.2–2.6 t/m$^3$ respectively.

Oil shale calorific value is about 7.5–18.8 MJ/kg (dry basis)

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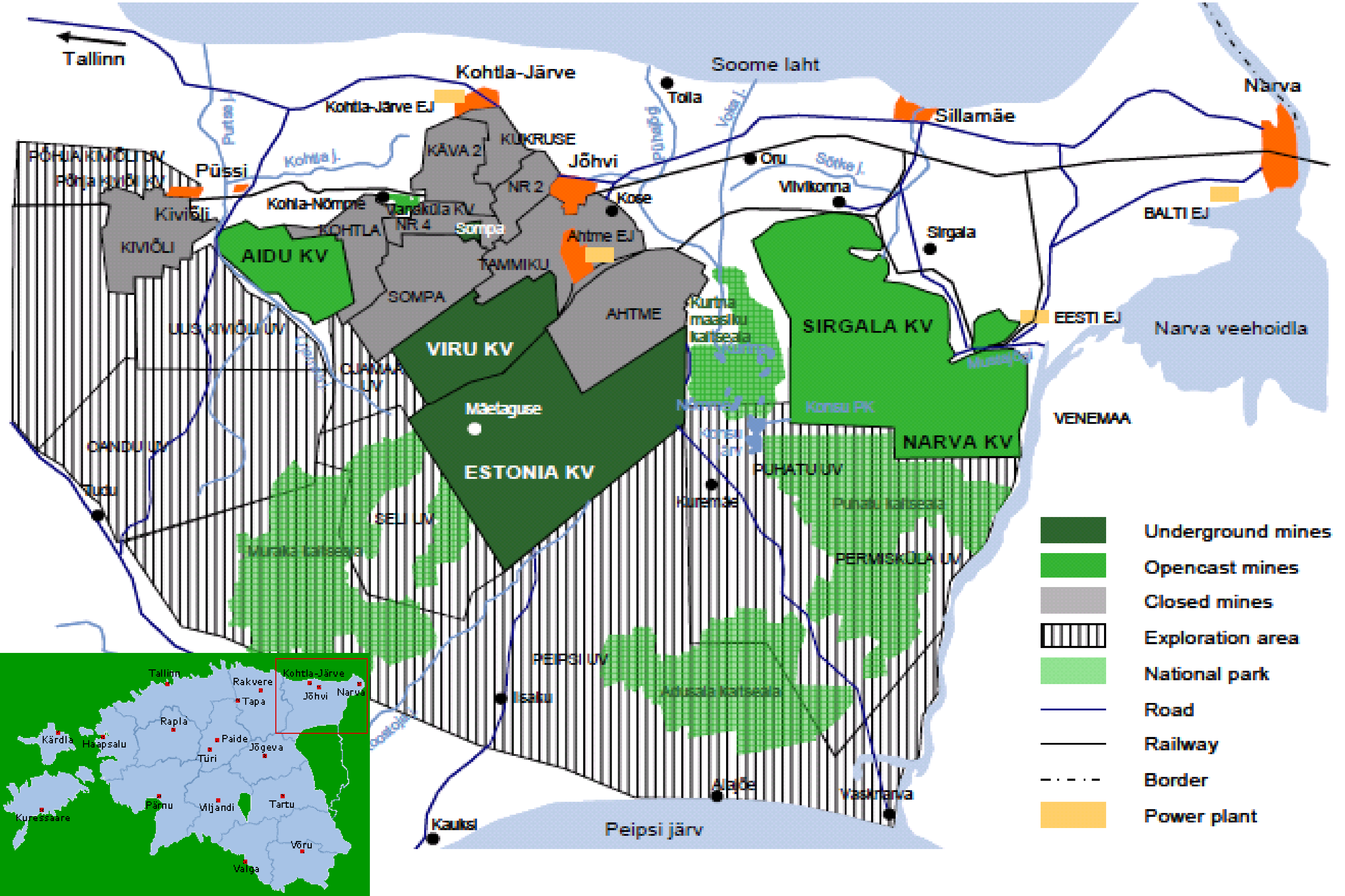
# Oil shale deposit map



# Why longwall mining?

The depth of commercial oil shale bed is increasing southwards in the Estonia deposit. In Estonian practice the economically reasonable depth of oil shale bed for open cast mining is up to 30 m.

In the greater depths underground mining methods are employed. The mining front in Narva open cast is approaching this limit, e.g. the thickness of overburden is reaching 30 m.

Also in the south-west part of the open cast the oil shale reserves are covered with peat resource, and there the underground mining might be the only way to extract the oil shale resource without destroying the upper peat layers.

Eesti Energia AS is planning to test longwall underground mining (longwall punch mining) method as a potential technology for oil shale extraction from higher depths.

The preferred option is to keep/increase the flexibility of capacity at our Narva open cast Mine by introducing longwall underground mining together with surface strip mining.

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# Why longwall mining?

Room and pillar mining is one of the oldest mining methods and currently widely used in Estonia for oil shale mining.

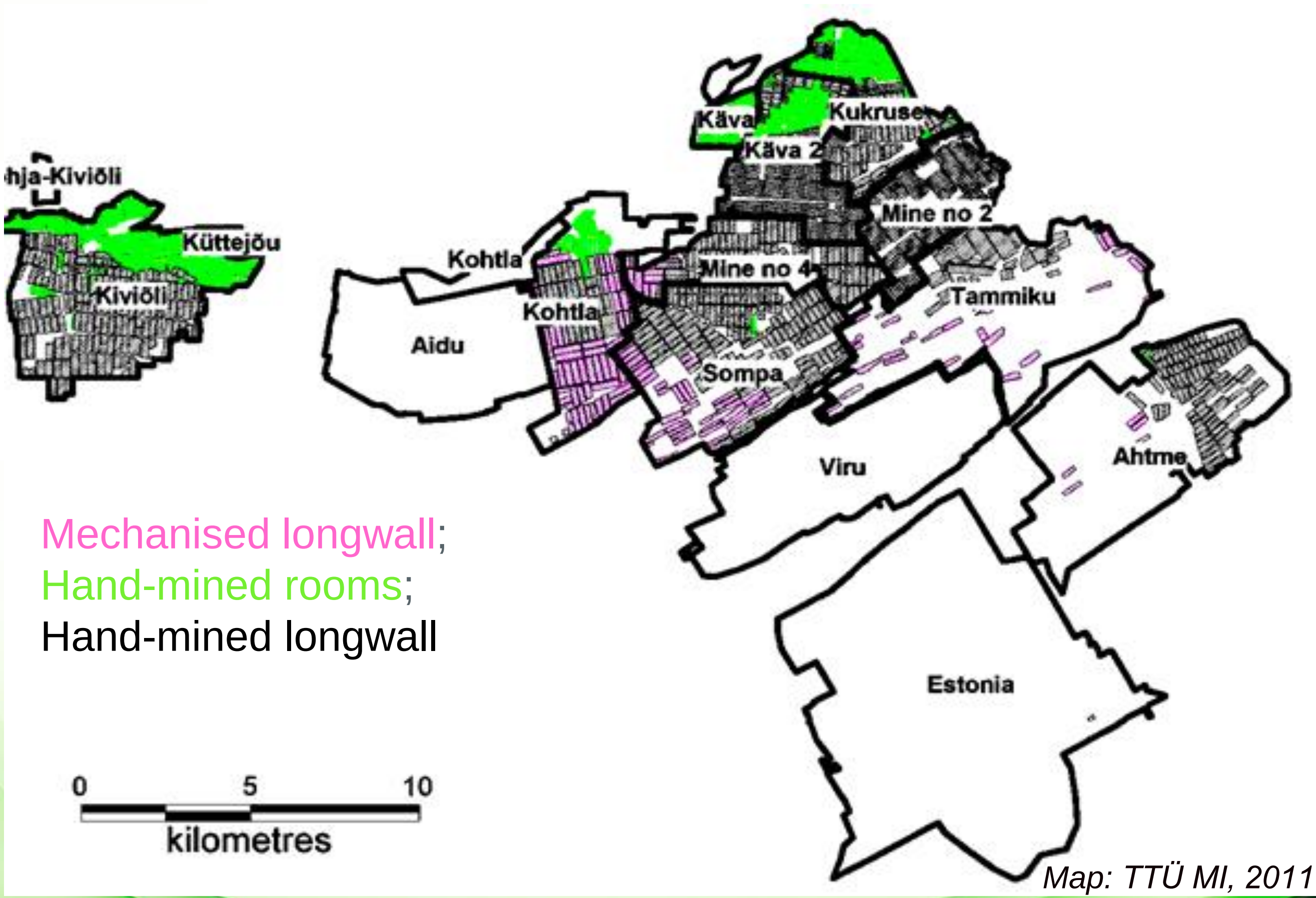
With greater depths or with not stable main roof (Narva´s case), larger pillars are needed, which would decrease the recovery rate from 70-80% down to 40-60%.

As the roof is not stable, the room-and-pillar mining did not suit with principles of greater recovery rates (>85%) at Narva. Currently the oil shale recovery of Narva open cast mine is about 85%.

The strip ratio of Narva open cast mine increases along with the depth in south-west direction, thus alternative economical mining methods must be sought.

# Oil shale longwall mining 1970-2000

We are familiar with longwall mining.
During the past three decades 1970-2000, the undermined area with mechanized longwalls in Estonia was about 14 km$^2$, which corresponds to 40 mln tonnes of sellable oil shale. The mechanized longwalls were mostly used in areas with shallow depths with hard geology, where conventional room-and-pillar mining was not suitable.



*Map: TTÜ MI, 2011*

Underground mining with longwalls:

- Kohtla 46%
- Sompa 25%
- Tammiku 19%
- Mine no 4 6%
- Ahtme 4%
- Estonia <1%

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# Geotechnical Information

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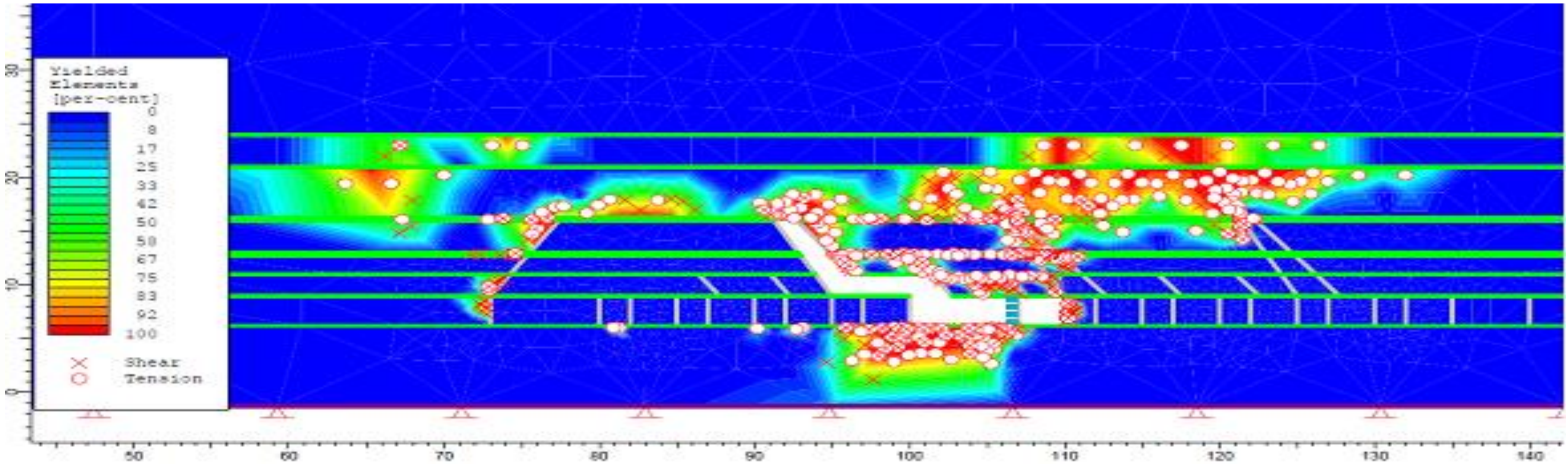
The first potential risk considered with Narva Longwall Project is the possibility of abnormally high support load in shallow depths, resulting from the lack of an abutment arch.

Several mines like Kohtla, Sompa and Tammiku have extracted oil shale by longwall methods at less than 35m depth.

These mines reported no abnormal support load or face deterioration due to the shallow depth. Water ingress from overlying water courses was the main operational problem in these mines.

# Geotechnical information




The model verification is described in Geotechnical report by modeling underground mining and roof collapsing tests that were conducted in Tammiku oil shale mine in 1980s.

The Hoek-Brown failure criterion was applied in the model. It can be applied to the rock masses which have a sufficient number of closely spaced discontinuities and similar surface characteristics to assume the isotropic behavior involving the failure of the discontinuities.

When the structure which is being analyzed is large and the size of the block is small in comparison, the rock mass can be treated as Hoek-Brown material. The Finite Element Method (FEM) modeling was performed using Phase2 software.

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# The soils and rocks encountered in the Narva open cast area

| Geotechnical unit in model | | Geological unit | Soil and rock type | Layer number |
|---|---|---|---|---|
| Soil overburden | | Quaternary cover | fill and topsoil | Layer 1 |
| | | | peat | Layer 2 |
| | | | sand | Layer 3 |
| | | | clayey silt, silty clay | Layer 4 |
| | | | till | Layer 5 |
| Bedrock overburden | Narva Stage | Narva Stage | marl and dolomite | Layer 6 |
| | Main roof | Kukruse Stage | limestone | Layer 7 |
| | Immediate roof | | limestone with kukersite | Layer 8 |
| Mined oil shale bed | | | kukersite oil shale | Layer 9 |
| Footwall | | Uhaku Stage | clayey limestone | Layer 10 |

The soils and rocks encountered in the Narva open cast area are divided into ten layers based on different properties and geological genesis.

At the same time the geotechnical model contains six units: overburden (soil and rock overburden), main roof, immediate roof, mined commercial oil shale bed and footwall.

The relationship between these classifications is shown in Figure.

Commercial oil shale bed is covered with overburden. The upper part of overburden is composed of Quaternary soils and the lower part of sedimentary rocks.

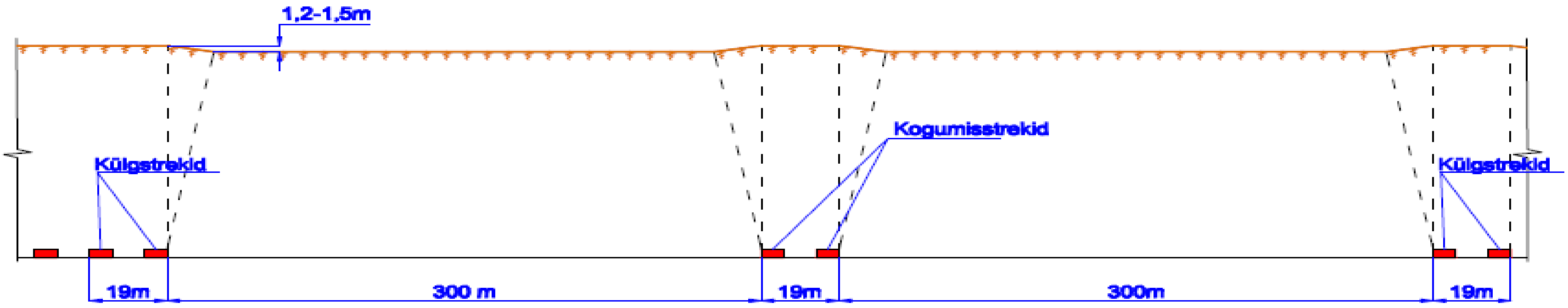
The Quaternary cover comprises of Layers 1–5: fill layer, topsoil and peat, sand, clayey silt/silty clay, till and other clayey sediments. Thickness of Quaternary cover is up to 22 m, but the average thickness stays around 7–8 m.

# Comparison of observed and modeled roof weighting intervals in Tammiku test mine

| First and periodic roof weighting intervals in Tammiku test mine | | Observed in test mining [a] | Modeled [b] |
|---|---|---|---|
| Immediate roof (Layer 8) | First roof weighting interval, m | 15-26 | 16-19 |
| | Periodic roof weighting interval, m | 6-9 [c] | 2.3 |
| Main roof (Layer 7) | First roof weighting interval, m | 27.6-33 | 34-37 |
| | Periodic roof weighting interval, m | 6-9 [c] | 8.8 |
| Main roof in two layers (Layer 7) | First roof weighting interval, m | - | 25-28 |
| | Periodic roof weighting interval, m | - | 6.5 |

The model was verified by modeling underground mining and roof collapsing tests that were conducted in Tammiku oil shale mine in 1980s.

# Resource Recovery




Increased resource recovery is often cited as a prime benefit of increasing longwall panel width. The logic being that each gateroad sterilises a portion of the resource in pillars and by reducing the number of gateroads, through increasing panel width, the amount of sterilised oil shale can also be reduced.

We will test the chain pillar partial recovery technology in Narva from the second neighboring longwall panel.
Therefore the influence of partially mined out chain pillar to oil shale technological losses is minimal.

# Anticipated Technical Information

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# Anticipated technical requirements

| | |
|---|---|
| Mining method | Conventional retreat longwall with chain pillar partial recovery |
| Number of maingate roadways | Two/Three (one-side for the first longwall) |
| Panel width | 300 m (including chain pillar) |
| Mining extraction range | Nominal 3.1m, minimum 2.6m |
| Panel lengths | 1,200 to 2,500 m, up to 4,500m |
| System cutting process capability | Bidirectional and unidirectional (selective) sequence mandatory |
| Extraction web depth | Nominal 800-1,000 mm |
| Roof support bearing capacity | From the past experience up to 100-120 t/m$^2$ (~1MPa), must be recalculated |
| Roof support in-service life | 30,000 cycles without loss of function |
| Shearer | Double-ended ranging arm/drum multimotor shearer |
| | Drum diameter and arrangement to be optimized to provide acceptable oil shale loading and operating capacities. |
| | Specific energy consumption from the past experience up to 0.9-1.8 kWh/bcm, must be recalculated |



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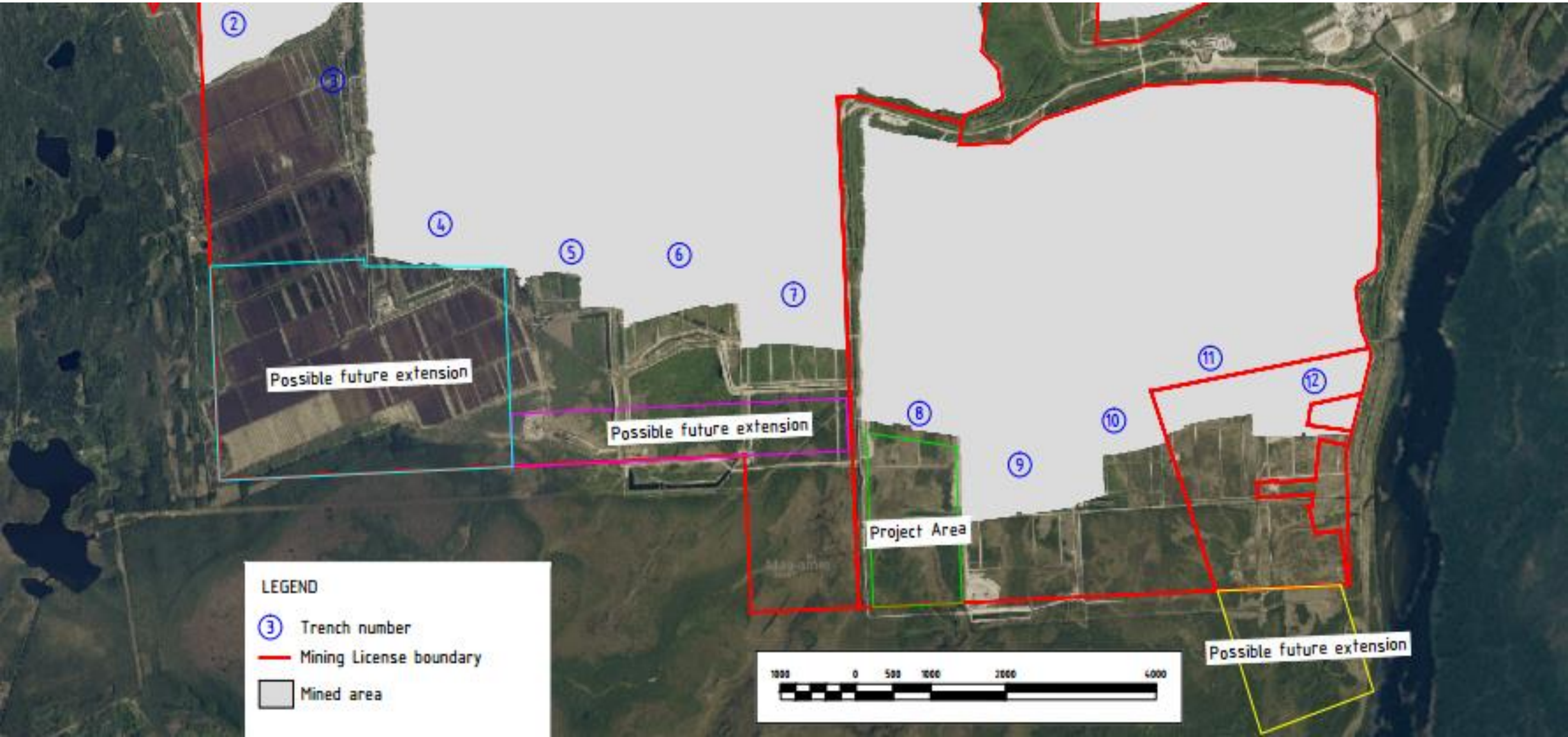
# Anticipated technical requirements

| | |
|---|---|
| Armored face conveyor (AFC) | Power rating to suit 2,500 t/h over full length of conveyor and volumetric capacity to suit 3,000 t/h short-term peaks |
| Seam composition | Oil-shale and limestone layer alternation. Oil-shale compressive strength up to 40 MPa and limestone up to 90 MPa |
| Seam pitch, degree | Up to 1 degree in south direction |
| Seam depth, m | Up to 37 |
| Opening of the reserves | Gallery (punch longwall) |
| Wateriness | High (>7m$^3$/t of ROM) |
| Methane danger | None |
| Dust explosion danger | Yes, irrigation needed |
| Roof | May be difficult-to-collapse |

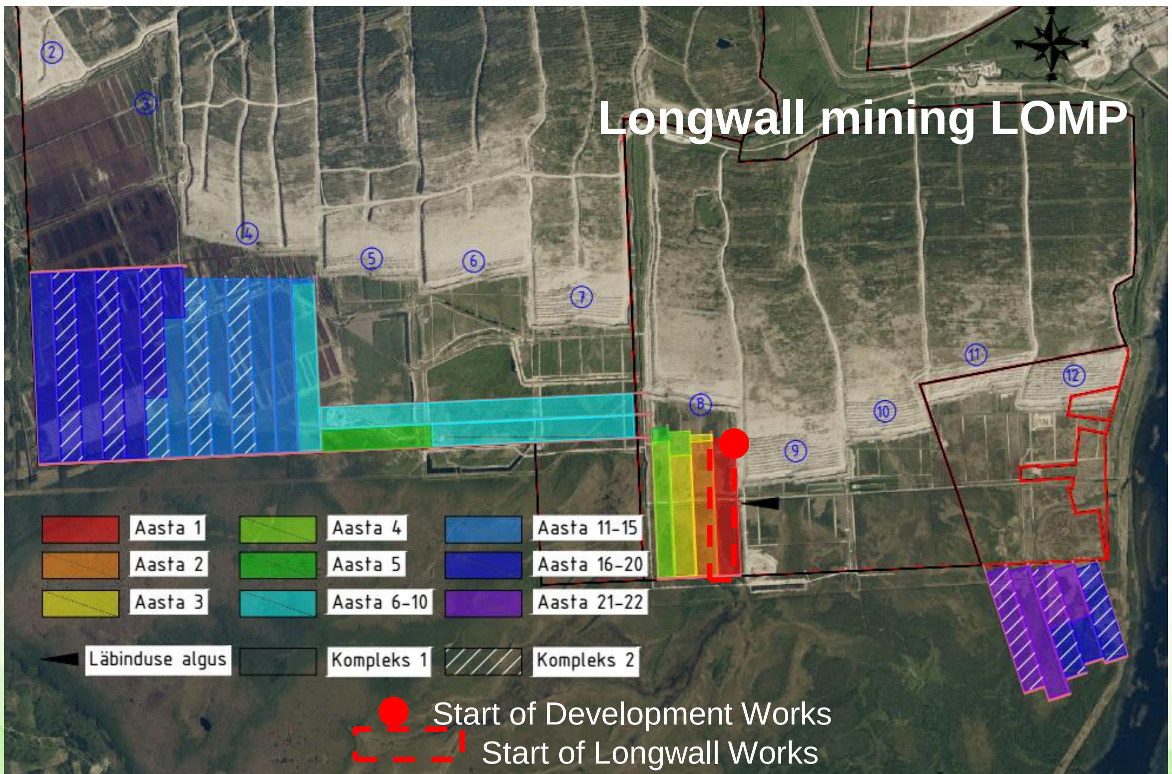
# Project area map

We anticipate Longwall Engineering for the Project area and for possible future extensions.



# Two panels/longwalls currently anticipated

| Description |
|---|
| • Longwall gate roads development – 2 brigades<br>• Start of Development Works– [Q3] 2017<br>• Longwalls available amount up to – 2<br>• Start of Mining Works– 01/2020 first longwall – trench nr 8; 01/2032 second longwall – trench nr 4<br>• Longwall width – 300 m |




| Year | RoM, TOTAL<br>x1000 t |
|---|---|
| Year -2 | **188** |
| Year -1 | 375 |
| Year 1 | 3 566 |
| Year 2 | 3 326 |
| Year 3 | 3 169 |
| Year 4 | 3 037 |
| Year 5 | 2 979 |
| Year 6-10 | 16 520 |
| Year 11-15 | 24 460 |
| Year 16-20 | 29 964 |
| Year 21-22 | 8 386 |
| TOTAL | **95 971** |



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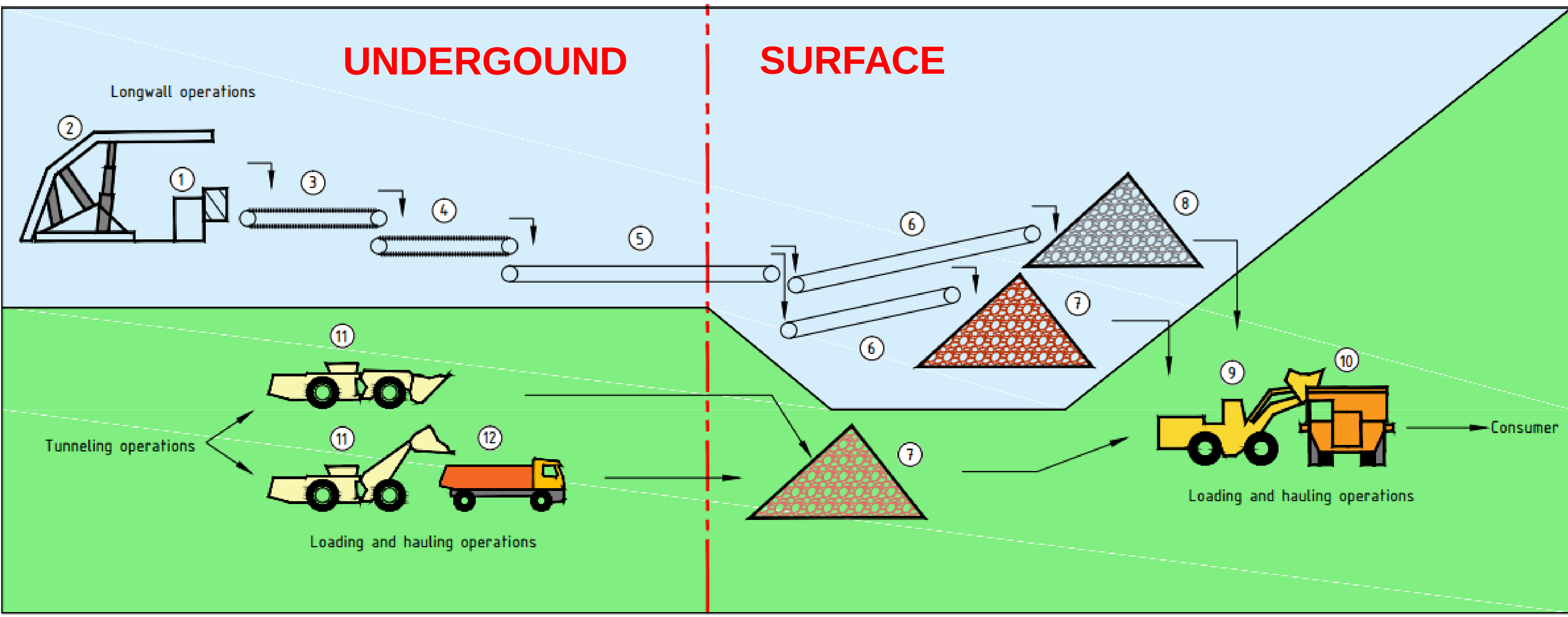
# Narva longwall mine battery limits




| Nr | Equipment name |
|---|---|
| 1 | Shearer |
| 2 | Powered roof support |
| 3 | Armored face conveyor |
| 4 | Stage loader |
| 5 | Belt conveyor |
| 6 | Stockyard formation conveyors |
| 7 | ROM/OS stockyard |
| 8 | Limestone stockyard |
| 9 | Wheel loader (7m$^3$) |
| 10 | Off-highway truck |
| 11 | LHD truck |
| 12 | Truck |

Contractor's Battery Limits

Owner's Battery Limits

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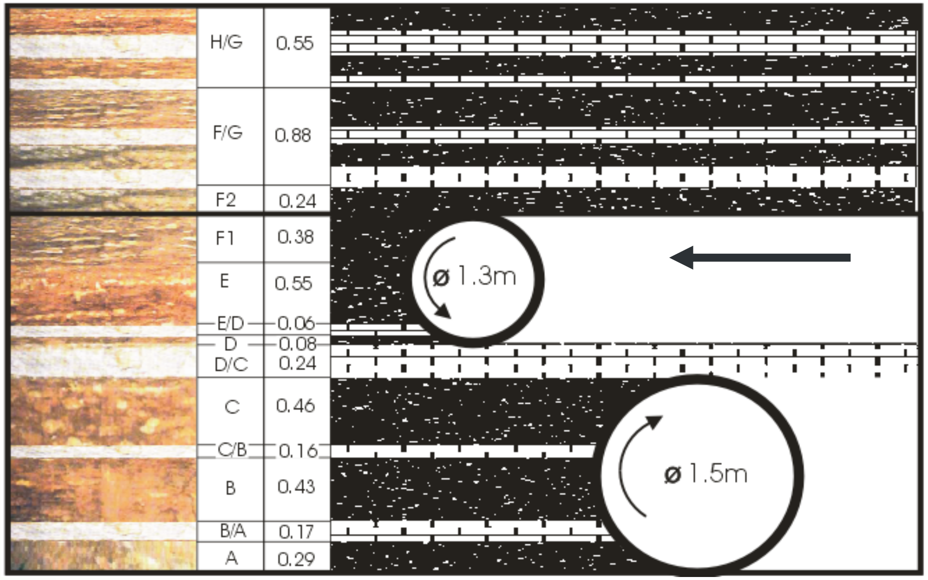
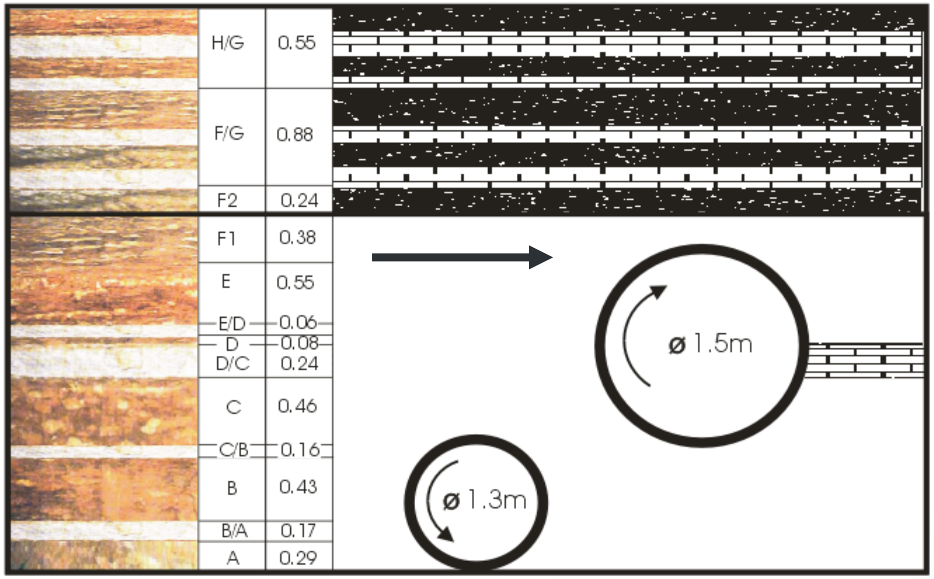
# Selective mining-
# unidirectional sequence *(example)*



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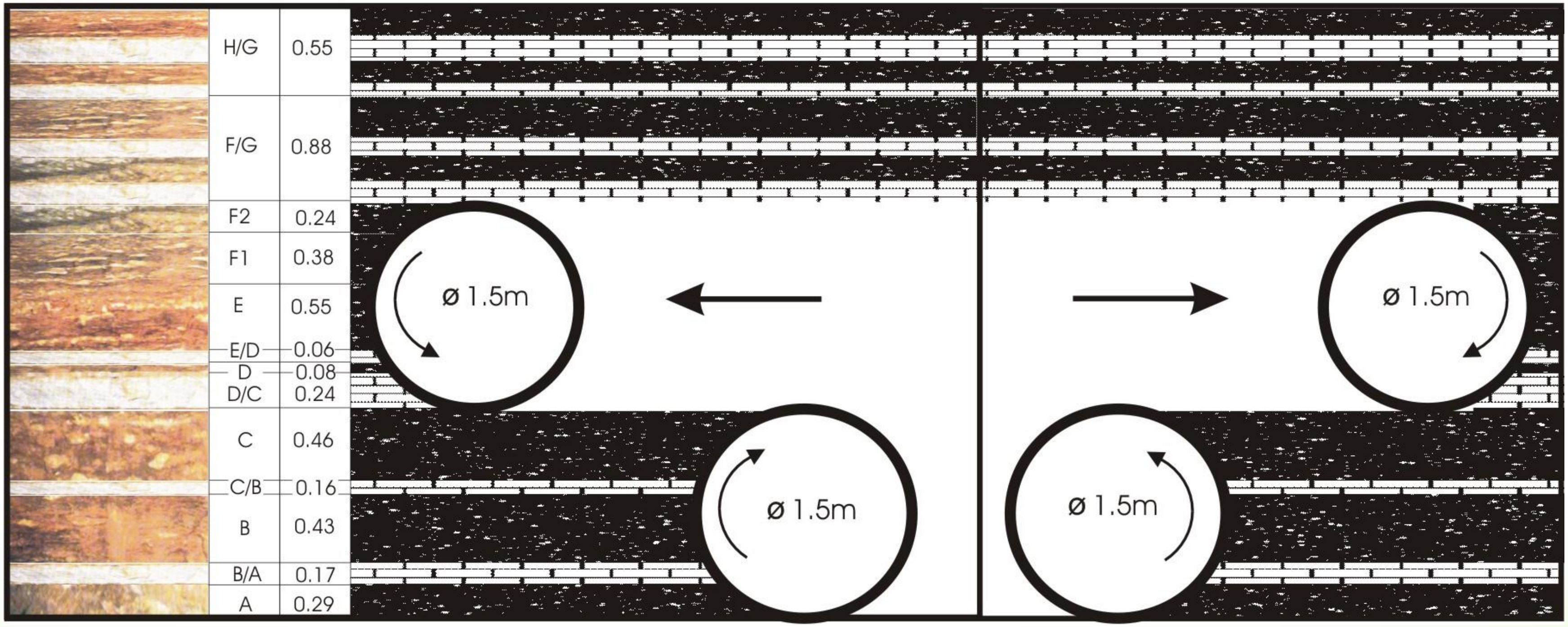
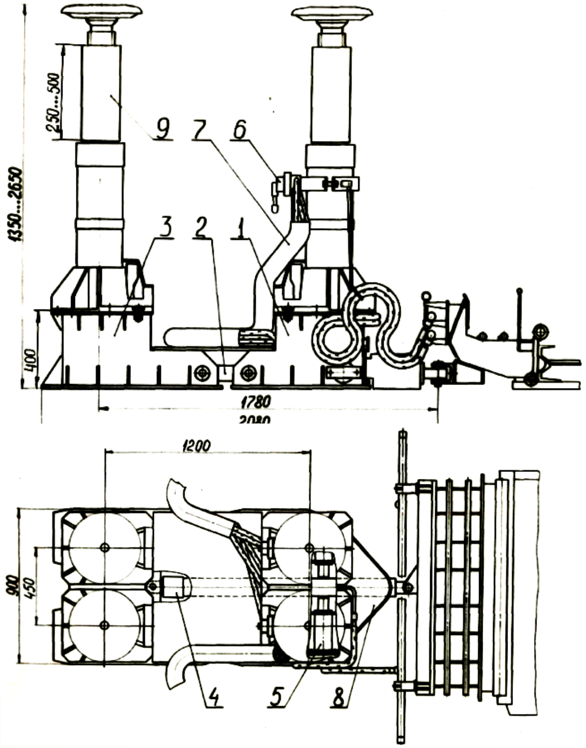
# Full seam mining- bidirectional sequence *(example)*



# Photos of past experience in longwall mining in Estonia

# Oil shale longwall mining 1970-2000





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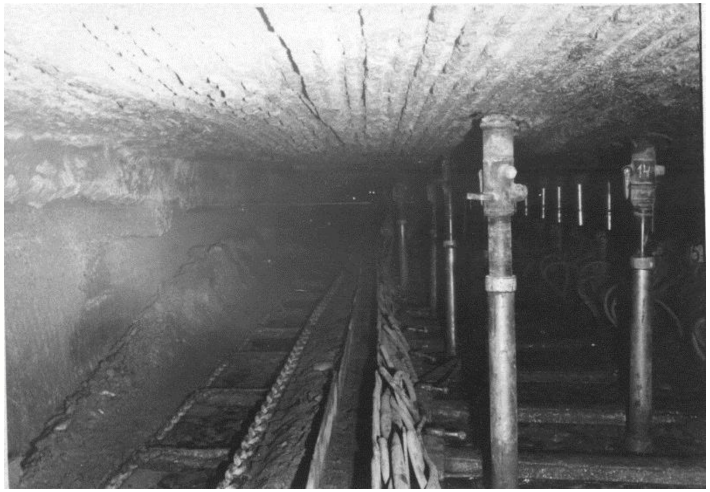
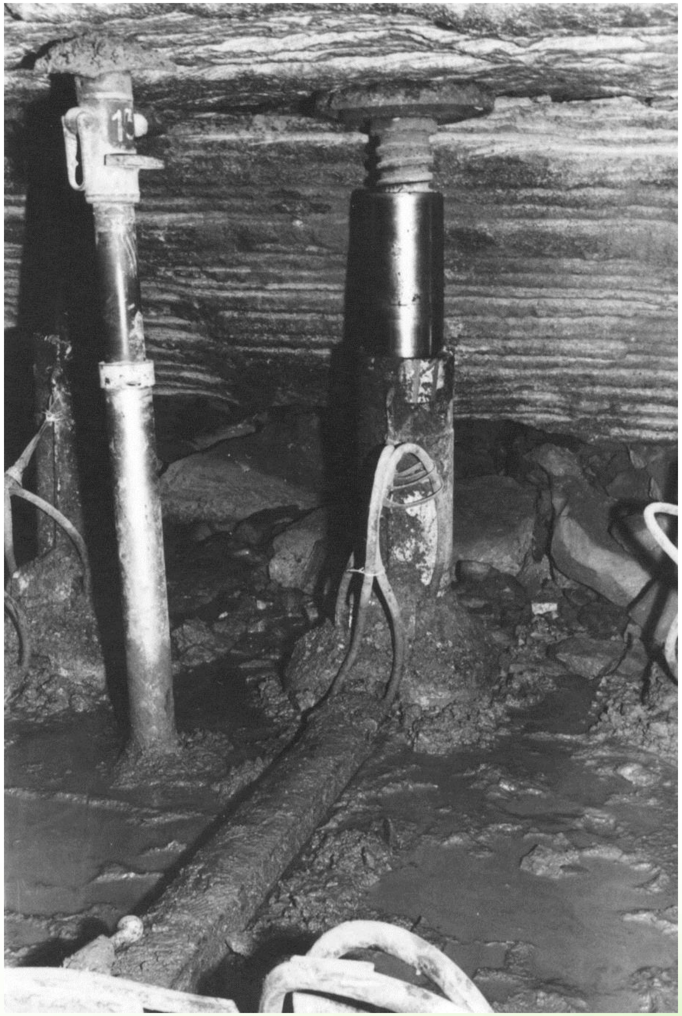
# Oil shale longwall mining 1970-2000





# Thank You!

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