Quaternary and Paleozoic Mineral Resources of the Harjumaa County, Estonia

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Abstract – Harjumaa County is located on the southern shore of the Gulf of Finland and has the highest density of population in Estonia. Road, industrial and living building need big amounts of building materials, about 2.1 million tons yearly. Five Middle and two Upper Ordovician quarries produce aggregate from limestone. The Middle Ordovician limestone is the best building stone of Estonia and is used from 1219. Limestone quarries are located along the main roadways, for their reconstruction is used the bigger part of extracted bedrock. Quaternary sediments are the main source of natural gravel and sand, in the Harjumaa County now are excavate sand-gravel sediments in 27 open pits. Deglaciation in the North Estonia is marked by two stadials, Pandivere and Palivere. The resources of sand and gravel are big enough, the are located along the roadways, the problem is that the deposits are not developed equally, sandy are common in the eastern part of county, gravel along the roads to Tartu and Haapsalu. Some marine sand-gravel deposits improve the situation in the western part of county.

I. THE LOCATION OF HARJUMAA AND ITS NEED IN MINERAL RESOURCES
Harjumaa County is located on the eastern coast of the Baltic Sea, in the northwestern part of Estonia and on the southeastern seashore on the Gulf of Finland. The population of county exceeds 530 million citizens, it make up with capital-city Tallinn (population about 400 000 people) together about 40% of Estonian population. Tallinn has international harbor, airport, railway connection with Narva, Tartu, Valga, Parnu, Viljandi, thick network of roadways and local roads. After joining to European Union in 2004 was initiated renovation of all types of transport, road- and railways, airfields and harbors. This action is financially supported by EU.

Intensive building needs different special materials: gravel, sand, aggregate etc. Estonia does not have outcrops of hard crystalline bedrock, for highway is used mostly limestone and dolostone aggregate, only for covering is used granite and other hard magma rocks from Scandinavia. From 2001 the mining of building materials grew very quickly up to 1.80 million m3 carbonate raw materials in 2007 and after that fall down up to 0.78 million m3 in 2010. Some growth in needs was noticed in 2011, 0.85 million m3 limestone was mined. During years 2006-2010 Harjumaa County excavated 65.8-67.5% of all carbonate raw materials of Estonia, only in 2011 it fall up to 61%.

Due to the last continental glacier deglaciation the ice margin had two temporary stagnations in Harjumaa County, Pandivere and Pandivere Stadial. Both they formed long belts through the county and contain large deposits of gravel and sand. In 2008 open pits of county excavated 1.96 million m3 of building sand (71%) and 49 000 m3 of filling sand (13% of total product of county), in 2010-2011 building sand excavation fall down to 0.61-0.68 million m3 (36% and 30% from country product), but filling sand part grew up to 0.39 and 0.36 million m3, it formed 36 and 37% from total excavation in Estonia. Building gravel excavating was biggest in 2007 – 0.37 million m3 (20% from all country’s amount), in 2010 was excavated only 0.14 million m3 (10%) and in 2011 – 0.22 million m3 (16% in Estonia). The bigger part all of excavated materials are used in civil, industrial and road building, only renewing of road network and railways needs many million m3 of building stone, gravel, sand and other materials. After the Ida-Virumaa (North-East Estonia) with extracting more than 15 million tons of oil shale yearly, Harjumaa County is keeping second place in total mining and the first place in raw building material mining.

Geological Background
Geologically territory of Estonia is situated in the NW part of the East-European Platform, where Paleoproterozoic crystalline basement is formed in the Svecofennian orogeny, 2.1-1.81 Ga ago, and was intruded by postorogenic rapakivi granites and mafic intrusions and dykes of age 1.67-1.47 Ga [1]. The youngest mafic diabase dykes are of age 1.3 Ga. During the long, 665 Ma, break in sedimentation were removed away by erosion about 15 km of the top of high Svecofennian Mountains [2]. On the surface became crop deep roofs of strongly deformed granulites and metamorphic rocks of amphibolite facies with crust of weathering up to 148 m thick [3, 4, 5]. The crystalline basement in the studied part of the Estonia is present at depths 125-280 m below the sea level and dipping southwards, together with the overlying sedimentary cover, with an inclination of about 2.5 m per km.

Sedimentary bedrocks are represented here with Ediacaran system of Neoproterozoic (635-541 Ma) Vendian complex and with the oldest, Cambrian and Ordovician series of Paleozoic system, 541.0±1.0–443.4±1.5 Ma [6]. At the beginning of Rodinia’s supercontinent break up at about 800 Ma, Protobaltica remained attached to Laurentia, until became independent at between 570-550 Ma. During the Cambrian and Ordovician Baltica drifted northwards from high to low southern paleolatitudes [7,8]. In Ediacaran Period, Cambrian and Lower Ordovician time Baltica stayed in the cold climate and there might form only terrigenic sediments, presented by sandstones, aulacitites and claystones. The thickness of these clastogenic sediments is up to 220 m [9]. In the Lower Ordovician composition of rock is more diverse: quartz and glauconite sandstone, clay, kerogenic argillite [10]. From Middle Ordovician up to end of Silurian Baltica drifted to equator and the sequence consist only carbonate bedrocks. During the Late Silurian to Early Devonian time took place oblique collision between the Baltoscandian margin of Baltica beneath Laurentia, crust become thicker and less density. Scandian event of Caledonian Orogeny reflected in Estonia with folding, faulting and blocks uplifts in the southeastern
Estonia and also with sea regression in Late Silurian in the northern and eastern Estonia to the Baltic Syncline at about 427 Ma ago [6]. During the 30-35 Ma break in sedimentation Ordovician carbonate bedrock were eroded up to oldest Upper Ordovician layers, which in north-eastern Estonia at short Middle Devonian transgression were covered by dolostones, sandstones and clays of the Narva Stage. Devonian Sea transgression did not reach Harjumaa territory, the weathering and continued up to Quaternary Epoch [11].

Quaternary System began 2.588 Ma ago, there are fixed many long periods of glaciation (up to 31), which alternated with much shorter interglacials. During last 425 000 years have been 5 glaciations and soon is finishing the fifth interglacial. Continental glaciers eroded and transported away all weathering crusts and bring to Estonia boulders, gravel and sand size material from Fennoscandia and from bottom of Baltic Sea. Deglaciation of the Pandivere Stadial is related to two levels of glaciofluvial deltas, where upper level, 70-80 m above sea level, has contact with glacier slope, and the bedding is dipping to south slope. The lower level, 45-48 m, formed streams northwards and transported glaciofluvial deposits to northwest back to opposite direction (Figure 1), into lowering ice lakes [12]. The youngest Palivere Stadial sand and gravel deposits formed the same time with Salpausselkä ridges [13]. Some sand and gravel deposits are in origin marine sediments. In Holocene, during last 11 700 year, in Estonia is going formation thick peat deposits, but county is not very rich by peatlands.

II. SHORT HISTORY OF LIMESTONE USING IN THE HARJUMAA COUNTY

The first using of local bedrock were fixed at the end of younger Bronze Age, when plate-like carbonate stones removed from fields and put in piles or a low stone wall around the fields. Limestone graves were usual for some places in the North Estonia, near the Tallinn and some hundred years before our era the same bedrock walls protected the fortified settlement Asva in Saaremaa Island. In ninth-eleventh centuries local limestone was used for building of 7-10 m high walls around the Valjala and Varbola strongholds. Both forts have in limestone deep wells, which are preserved up to now [14].

After invasion and occupation the small settlement in the place of Tallinn in 1219, the Danish king Valdemar II at once began to build a large and strong limestone castle-citadel on Toompea. The building was ready in 1227. The time up to end of 13th century was very successful for limestone building. After building numerous churches in Tallinn and other places in Estonia local limestone became the best building stone. At the beginning limestone was broken on the central limestone hill of Tallinn – Toompea, later stone from quarries on the Lasnamäe alvar was transported by horses. In 1248 Tallinn obtained Lübeck’s Rights and became an important trading harbor in the Baltic Sea. In 1311 was initiated building a limestone wall around all city and in 1355 the 4.5-8.5 m high wall with 6 wall-towels and 8 gate-towels was ready. Later the city-wall was strengthened and many
new towels were added. In 1530 the wall has length 2.35 km, was 3 m wide, 13-16 m high and has 46 towels. Military importance loosened city-wall in the first half of XVIII century. A lot of limestone was used for building houses, basement floors and cellarrage. Limestone was the main building stone in Tallinn up to beginning of XX century. The Middle-Ordovician limestone is well saved in churches, houses and city-wall. The central part of Tallinn, so named Old Tallinn, is listed into UNESCO Historical Heritage List.

III. CARBONATE BEDROCK RESOURCES AND MINING

Crystalline magma bedrock is the best material for building, especially for road-building. They are hard and have needed physical-mechanical properties, stay insoluble salty water and do not decompose after multiple freezing. Unfortunately these bedrocks in Estonia are covered by 125-150 m sedimentary bedrock cover. The deepness of gneisses and granites in not big and underground mining may be economically useful and becoming free space may be used for accumulative electric power-station or fuel storage, if in needed way organize mining [15]. Many people are working now in limestone quarries, the most of them will loose job, but they may find work in granite mine, when it will be open. The Neeme granite massif is ready for mining.

During 800 years Middle Ordovician carbonate bedrocks, of age 470.0 ±1.4–458.4 ±0.9 Ma, have being the main building stone in Harjumaa County. Middle Ordovician in the North Estonia is represented by 5 stages (from oldest): Volhov, Kunda, Aseri, Lasnamäe and Uhaku.

Fig. 2. Vão Formation limestone in Vão quarry, city part of Lasnamäe in Tallinn.

The limestone of every stage forms west-east direction belt with width accordingly to their thickness, all bedrock sequence is dipping southwards with an inclination of about 3 m per km. In Harku quarry total thickness of Vão Formation is 11.3 m and the width of outcropping belt about 4 km. Usually from Vão Formation limestone of Lasnamäe Stage and lower part of Uhaku Stage covers the upper part of the North Estonian Klint (Fig.2). The formation is represented by best building stones of Estonia. The compressive strength of this limestone is very high, 80-90 MPa across bedding and 50-70 MPa along bedding, it insoluble residue is 6-12% (mainly quartz grains from Fennoscandian Shield), water absorption about 1-2%, in argillaceous limestone – 2-3% and in dolomitized limestone 2-5%. Frost resistance is usually 25 cycles, sometimes 15 or 35 cycles. The most of Vão formation limestone is used for aggregate, but earlier often as stone for masonry, finishing slabs and also for gravestones, panels, finishing slabs, beautify frontals of buildings [14].

Only upper part of Uhaku Stage includes clayey limestone and seams of oil shale and marl intercalations and may not be used as building stone. All other types of the Middle Ordovician limestone and dolomitized limestone physical-mechanical properties allow produce aggregate of needed quality [14, 16] and extract stone together with limestone of Vão formation in quarries. In the Harjumaa County now are working 5 quarries on these bedrock: Harku and Vão surround Tallinn, and Maardu, Jägala ja Valkla along the roadway Tallinn-St. Petersburg. The distance from quarries to Tallinn is less than 40 km, so it is economically acceptable.

Upper Ordovician lasted about 15 Ma, from 458.4 ±0.9 to 443.4 ±0.4 million years ago. Ancient Baltica continued drift to equator and reached at Keila and Oundu Stages warm latitudes, it reflected in the first corals and bioherm complexes [8]. The oldest, limestone of Kukruse and Jaljala Stages contains some oil shale and are argillaceous, as well as upper part of Uhaku Stage. They may be used for local building, but for aggregate are too soft. Only Vasalemma Formation contains stone for industrial using, construction aggregate, building limestone and finishing slabs. Industrial limestone forms small lens-like bodies, which need manual sorting, it is possible if are needed very pure CaCO3 concentrate (98-99%) and customer will cover expenses. Last two year industrial stone is not extracted. Limestone for aggregate is extracted from Vasalemma Formation, in two quarries, Määra and Vasalemma, mostly for local road building. In some new quarries resources are estimated. One very perspective is Nabala mining field, because there is continuing renewing roadway to town Tartu. To get permission from local people is not easy, because local people will find different reasons, why the mineral resources must not be mined in this place. But not everywhere bedrock has needed strength and other properties. Every excessive km for aggregate transport make road building more expensive and need more time.

From Upper Ordovician carbonate rocks only Rõa Formation dolostone in Porkuni Stage may be used for building stone and finishing slabs, partly as industrial stone is possible extract limestone and dolostone of Rakvere and Nabala Stage and aggregate is possible to make from Rakvere, Nabala and Pirgu Stage limestone.

The southern part of Harjumaa County is covered by Lower Silurian limestone and dolostone, but density of population is low, to open new quarries are not planned.

IV. QUATERNARY SEDIMENTS AS RESOURCE OF GRAVEL AND SAND

Through the county spread two zones of the glacial stagnation, Pandivere and Palivere Stadials. Marginal forms of the Pandivere Stadial occur on the north-western slope of the Pandivere Height, in western Estonia the zone is traced near the Pärnu. The Palivere marginal zone is marked by marginal eskers in north-western Estonia and by large glaciofluvial delta's of Männiku and to east of Tallinn [17, 18, 19 etc.]. In the North Estonian Plateau covered by hard Ordovician carbonate bedrocks the thickness of Quaternary
cover is relatively thin, predominantly less than 5 m and in
alvars less than 1 m. In Tallinn are studied some valleys, buried by till and fluvioglacial sediments even up to 145 m
under the sea level (Harku Valley). In the zones of temporary
continental glacier stagnation are formed end moraines, glaciofluvial deltas and sandurs, other glacial sediments of ice
melting water. The zones consists the best sand and gravel
deposits, which thickness in such belts exceeds often 20 m.
Some sand deposits are situated in the modern sea, another
were formed in sea, but later after the regression of the Baltic
Sea remained far from sea.

All 27 at present working gravel and sand may be divided
to groups taking into consideration their position to stadial,
distance from ice margin and genesis. In the central part of
county between Pandivere and Palivere Stadial zones glacial
sediment forms four groups of deposits orientated in direction
of ice margin, NE 45-75º, during the deglaciation here.

Sediments near Pandivere Stadial ice margin contain more
gravel and clay than fluvioglacial sandy deposits. These
positions are taking Voose (Kuressaare) and Punamäe
deposits (Fig.1, 3). Next line on deposits is characterized by
variation of gravel part 20-45% and decreasing of clay
content up to 3-6% in Vahelaane and Kose-Risti open pits. In
Vahelaane open pit was possible to observe, how older
bedded fluvioglacial sands are deformed into folds, after that
their upper part eroded and covered by new layers of gravel
and sand (Fig.5).

In Sõmeru deposit clay content increases to 11% and gravel
decreases to 16%. To this group is possible join Vetla deposit,
with small clay and about 20% gravel (Fig.1). Next group
deposits: Pihuvvere, Piuga and Nõmmie are located about 10
km to north-west, every of them have different composition,
all on them are gravel open pits, excavated material contain
36-55% gravel, 4-19% clay and sand.

A group of five sand deposits of Palivere Stadial are
located near the Kuusalu, to east from Tallinn (Fig.1). It is
interest to note, that all deposits are located between
Pandivere and Palivere marginal zones, but more gravel
material contain deposits near the Pandivere zone and in
Hundiaugu deposit sand bedding was dipping to north-west.
When were formed these sandy sediments? All impurities in
Huntaugu sand are 2% clay and 0.5% gravel grains, Kuusalu
deposit – 1% gravel and 1% clay. To south-east the amount of
impurities raises, in Soodla deposit – 1% gravel and 5% clay,
in Raudoja – 4% clay and 16% gravel, in Poolvahe – 2% clay
and 16% gravel parts.

Three deposits near the sea shore are declared to be marine
genesis: Audevälg, Karjaküla and Tatramäe. Their clay,
gravel and sand content in all deposits is the same: clay – 5-
6%, gravel – 25-27%. Karjaküla deposit has primary more
thick fluvioglacial part with bedding dip to east-south-east at
angle about 25-27º, which is covered by 2-3 m thick
horizontal bedding sand and gravel deposits.

Fig. 3. Typical natural gravel of the Pandivere Stadial after sifting out of
sand part in Voose (Kuressaare) open pit.

The next group of deposits Seli, Suuresta, Vaidasoo and
Kõrnumäe belong to sandy deposits with some gravel content,
13-32%. One deposit from this group, Suuresõödi excavates a
good quality of gravel (46% gravel, 4% clay and 50% sand).

The Palivere Stadial marginal zone can be observed in
north-eastern direction from Matsalu Gulf to south of
Haapsalu to Loksa town. Two deposits are located on the
marginal zone, Kalda and Mustu. They both are typical
fluvioglacial gravel deposits, gravel content is 37- 60%, clay
– 3-10%.

V. CONCLUSIONS

Harjumaa County has large amount of different carbonate
bedrock and developed resources. All nowadays working
quarries are located in two zones, the Middle Ordovician Väo
Formation in the Lasnamäe and Uhaku Stages (5 quarries)
and the Upper Ordovician Väslemma Formation in Keila
Oandu Stages (2 quarries).

The main sources of gravel and sand belong to Pandivere
and Palivere continental glacier last deglaciation Stadials,
duration was not very long. The ice near the North
Estonian Klint after overcoming the Gulf of Finland had
relatively small clay content and sand near the Kuusalu
(Kuusalu, Huntaugu) and Tallinn-Saku is very high quality
for every kind of building. Harjumaa County is rich by sand
and gravel deposits, but gravel contains only some percent of
hard bedrock from bottom of Gulf of Finland and Scandinavia. Gravel is rich by carbonate pebbles, but after
transport and rounding saved only parts, which were more
hard and resistant. Big part of gravel deposits are not in work,
but are ready to begin excavating if will be needs.
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Fig. 5. Folded sand in the lower part is deformed into folds, later part of sequence eroded and covered by horizontal gravel and sand layers. Vahelaane open pit.