

Chemical stabilization of quick clay - a new approach

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Lime - Cement (LC) stabilization of quick clay

Quick clay is stabilized by stirring portland cement and/or lime into the formation. The cementitious materials spontaneously absorb pore water to hydrolyze, forming concrete minerals (including portlandite, tobermorite, and ettringite). Both processes stabilize the quick clay.

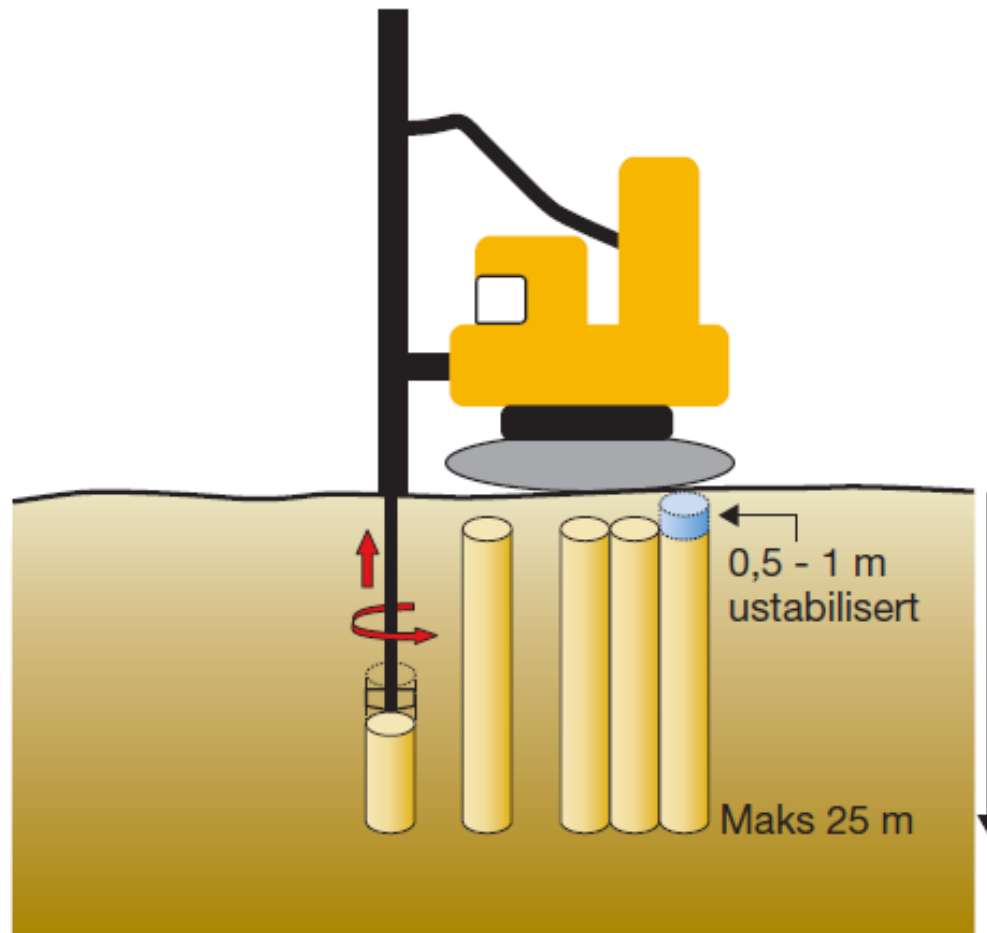


- The reaction is exothermic, and the formation is heated, thereby speeding up the chemical reactions.
- The pH increases to above 12, etching fine-grained quartz particles in the clay, and calcium-silicates are formed (in concrete terms: C-S-H).

‘Standard’: 100 kg cement per cubic-meter clay (in the drill hole); with the goal to obtain shear strengths >200 kPa. (e.g., 10 m deep hole with 60 cm diameter is ~3 cubic meter clay → 300 kg cement → 300 kg CO₂ emission)

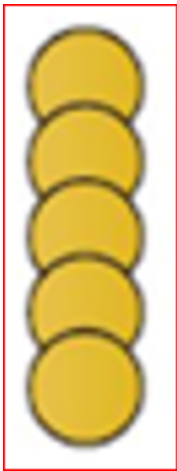
Leaching of calcium ions contribute to stabilize the clay outside the cemented zone, because Ca⁺⁺ is four times more efficient to flocculate clay compared to Na⁺ ions (van Olphen, 1963).

**Lime - Cement (LC) piling. Drilling depth commonly less than 25 meter.
Borehole diameter 0.5 to 1 meter, according to purpose.**

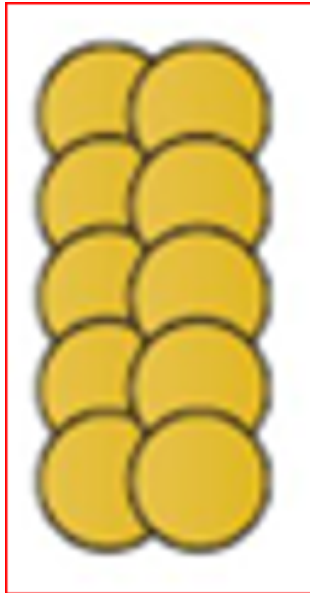


LC piling designs: “locking the quick clay” within subsurface walls

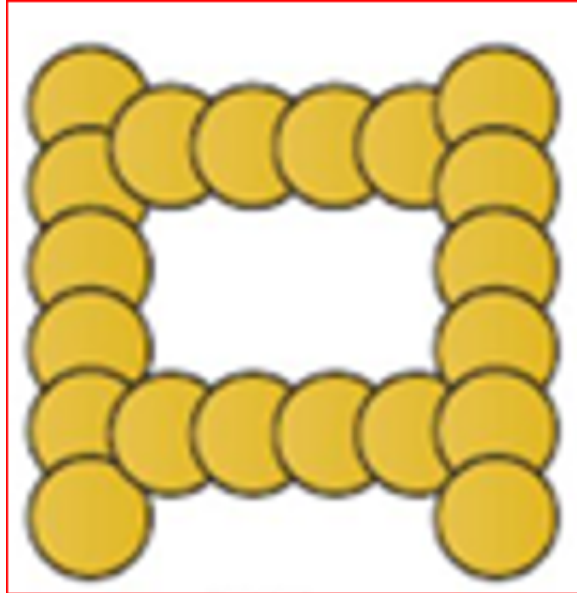
rows of
piles



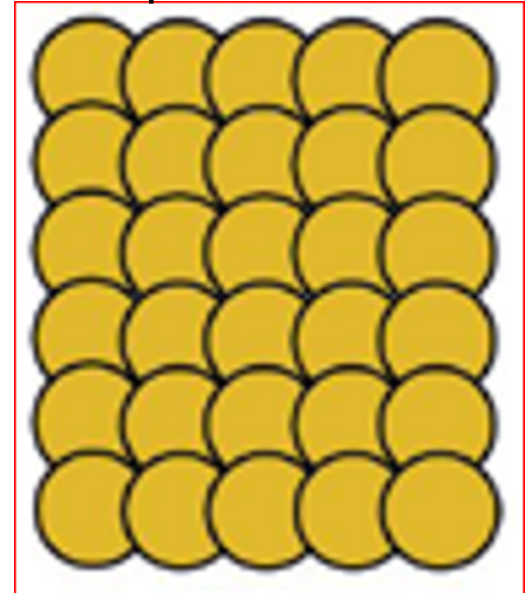
double
rows



pile
lattice



block of
piles

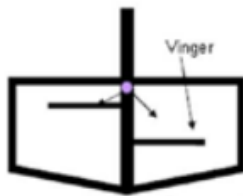
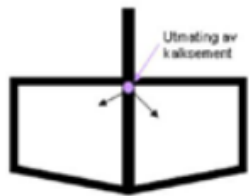


Commonly used overlap between piles is 10 cm (4 inch).

Consolidation of quick clay for the new E6 at Mosjøen (bridge foundation).

A drilling rig, with a 30-meter-high derrick. To the left is a tank with lime (JLE AS Company).

Whisks to be mounted on the drill pipe: 0.5 - 1 m diameter. Nozzles indicated.



«Standard» visp

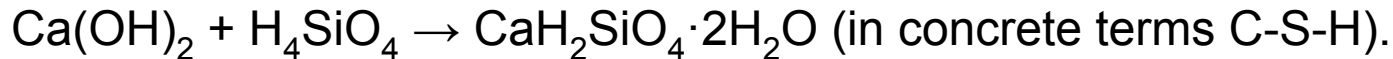


Part 1: New cementing approach with the purpose to:

1. Increase safety during drilling
2. Speed up drilling progress
3. Reduce CO2 footprint
4. Reduce wear and tear of drilling equipment
5. Improve the mixing of cementitious powder into the clay.
6. Reduce pressure build up when injecting cementitious powder.

Item 1 and 2: Faster hardening (hours rather than weeks) of the drilling site by adding alkali-silicates (dispersion agent) to the cement. This enables faster and safer forward moving of the drilling rig.

The pozzolanic reaction in concrete occurs when CaO (quick lime) reacts with water and silicic acid:



Tobermorite ($\text{Ca}_5\text{Si}_6\text{O}_{16}(\text{OH})_2 \cdot 4\text{H}_2\text{O}$) is formed in this way.

‘Fly ash’ is commonly added to concrete to improve this reaction.

An even faster reaction is obtained by adding **alkali-silicates** (‘waterglass’). This approach is taken here.

Item 3 and 4: Reducing CO₂ “footprint” by replacing more than 50% of the cement by papermill ash and alkali-silicates. Reduce the diesel consumption during drilling and the mechanical wear and tear on the drilling equipment.

This is achieved by the dispersion effect of silicates during the downward drilling, turning the clay into a “soup consistence”. This reduces the power needed for drilling.

Item 5: An improved mixing of the dry cementitious chemicals with the clay is obtained by stirring the low viscosity clay during the upward drilling, while the cementing powder is blown into the formation with an air compressor.

Item 6: Reduce pressure build up when injecting the cementitious powder. This is achieved by lowering the viscosity of the clay with alkali-silicates.

New cementing approach: initial testing in collaboration with NGI

A sample series of 3 specimens was prepared from the same quick clay sample.

Sample 1 (reference) corresponds to 100 kg cement/CKD per m³ clay (CKD is 'Cement Kiln Dust', also referred to as "Multicement").

The other samples were added less cement, which was compensated for with 'paper mill ash' and alkali silicate.

The 'Ash' component refers to papermill ash containing partly calcinated chalk (a waste product). 'Silicate' refers to a mixture of two industrial products of alkali-silicates.

Testing of shear strength for the entire sample series was carried out at NGI, Oslo, in Nov. 2019 and in Jan. 2020 (attn. B.K. Fiskvik Bache).

Values in the table are given in grams and correspond to kg per cubic meter clay. Test results are given in kPa after curing time of 10 and 28 days.

Sample No.	Samples tested at NGI January 2020 (attn. B.K. Fiskvik Bache).						
	Clay (g)	Cement/CKD (g)	Ash (g)	Alkali-silicate (g)		10 days (kPa)	28 days (kPa)
# 1.	1200	55	0	0		649	718
# 2.	1200	20	20	10		540	510
# 3.	1200	20	0	0		n.m.	225

Samples prepared Dec. 9th, 2019. Testing of two different alkali-silicates (x and y). Test results in kPa after curing in 12 hrs., 7 days, and 10 days.						
Clay (g)	Cement/CKD (g)	Ash (g)	Alkali-silicates (g)	12 hrs (kPa)	7days (kPa)	10 days (kPa)
1200	20	20	10 (x)	100	370	700
1200	20	20	10 (y)	110	245	600

Part 2: Quick glacial till versus quick marine clay



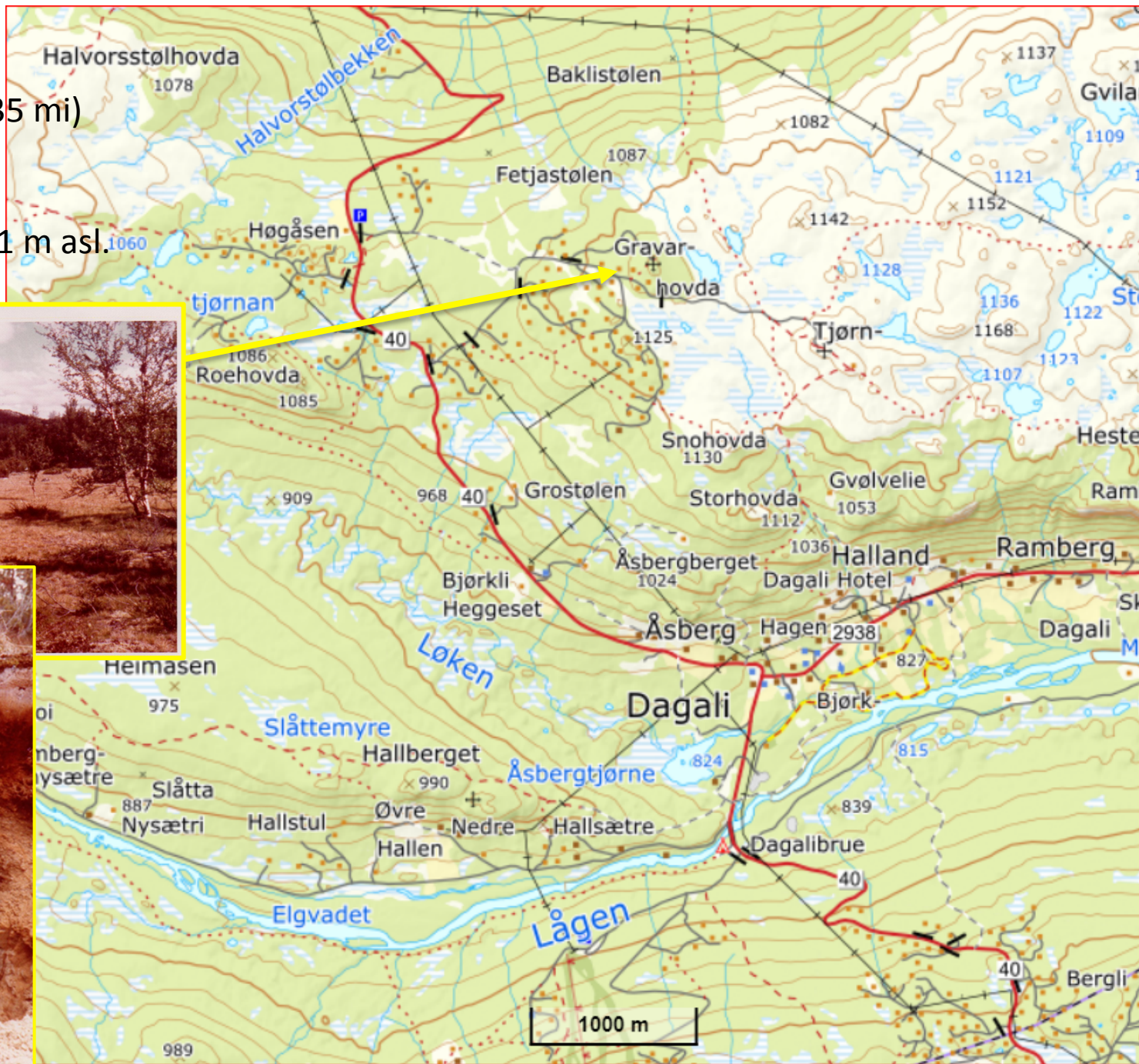
Fluidized till from Gravarhovda,
Dagali, with natural water saturation.



Quick marine clay from
Levanger, Mid-Norway.

Dagali: 220 km (135 mi)
NW of Oslo.

Gravarhovda: 1151 m asl.



In 2019, excavation work was carried out below Gravarhovda. During digging, the till masses "collapsed", and the excavator sank. The machine was tried to be saved with a new excavator, but it also sank, and so did the third. Fortunately, no one was injured.

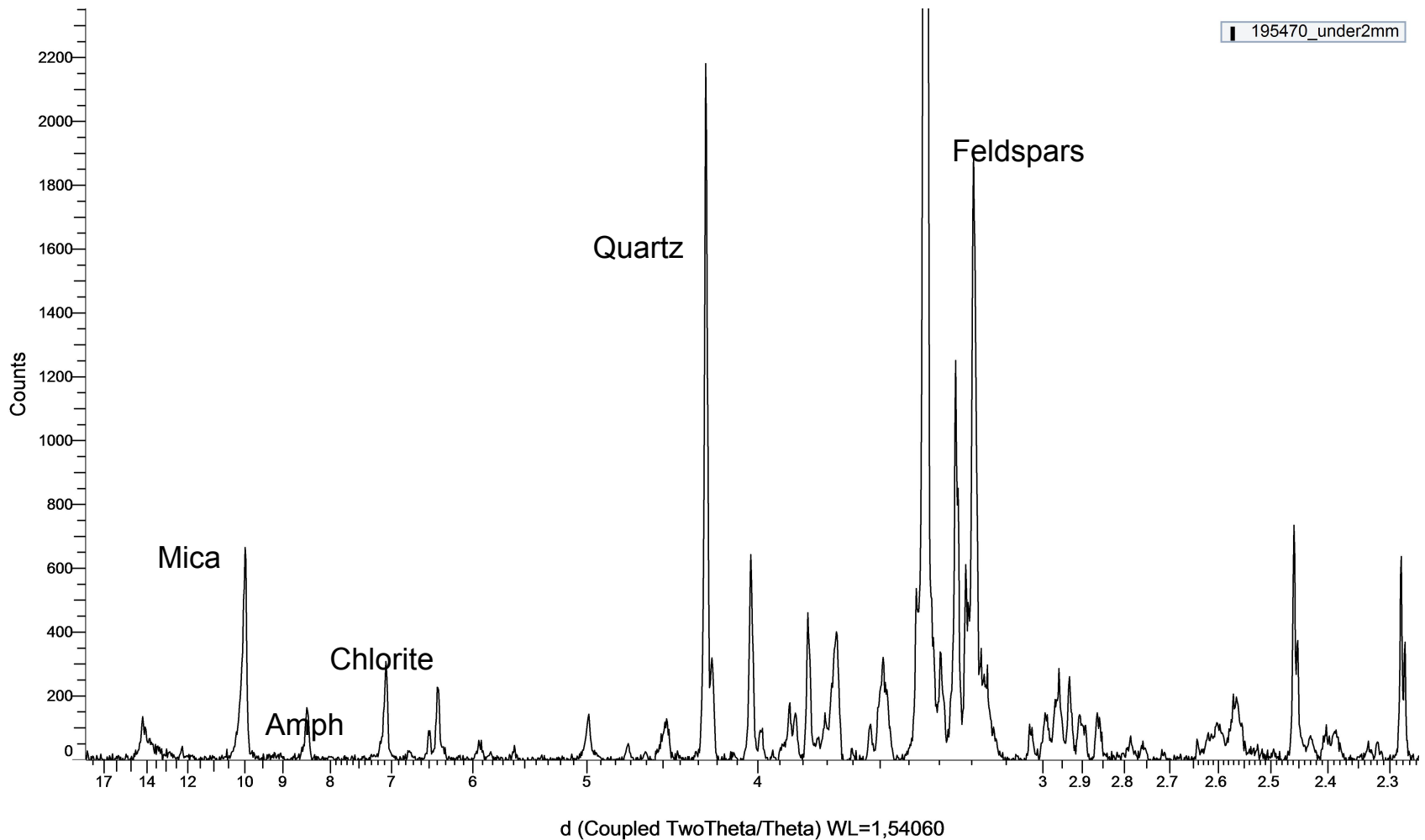


After the third attempt, it looked like this. The till was 6 to 7 meters deep at this location.



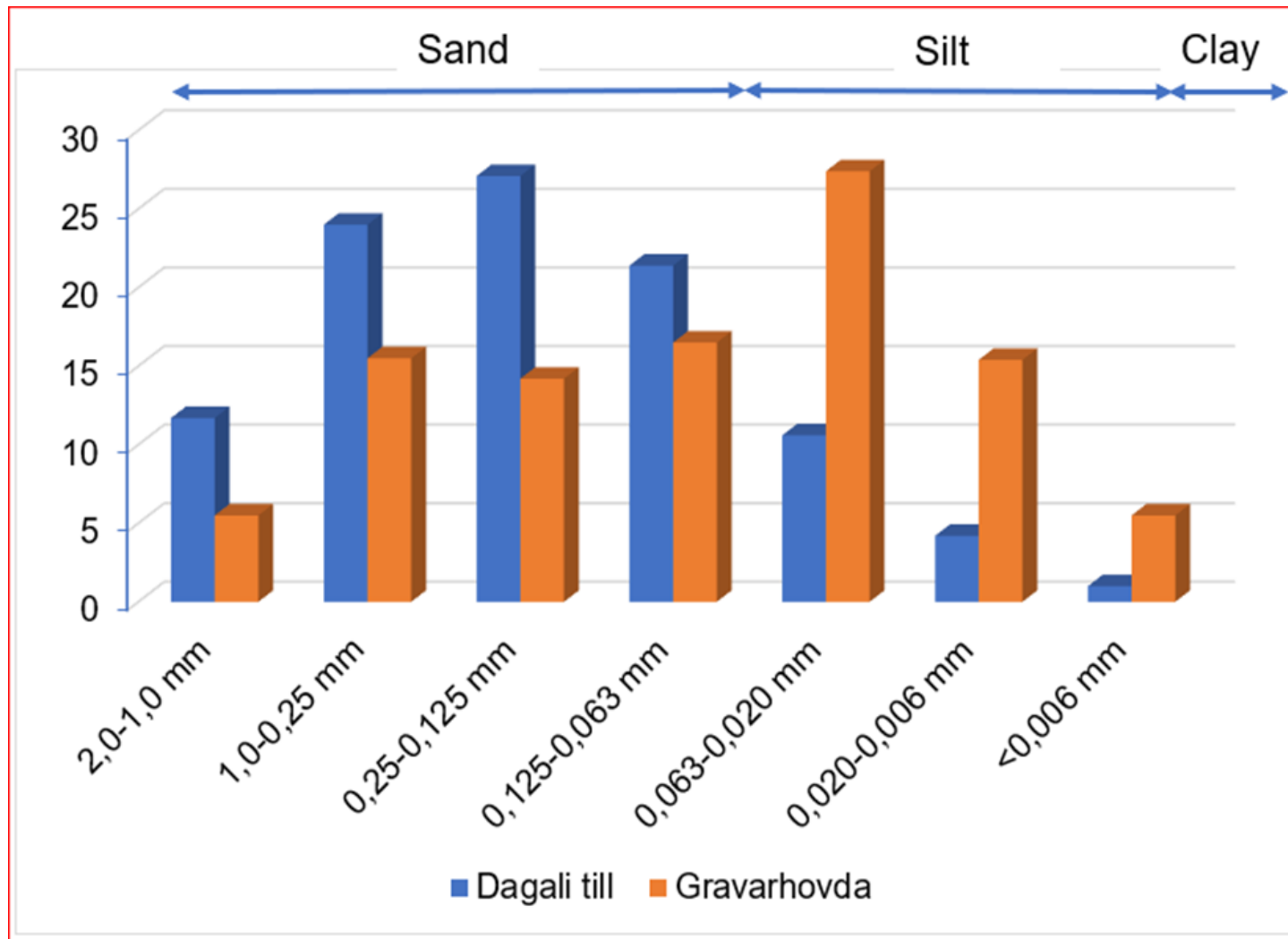


Melt-out till in Dagali. Cobbles and boulders amounts to ~70% of the weight.



Dagali «quick till», fraction <2 mm, show a mineral assemblage like all tills in the area – a grano-dioritic composition (similar to marine clay):

Quartz: 46%, K-feldspar: 13%, Plagioclase: 20%, Amphibole: 2%, Mica: 14%, Chlorite: 5%.



Bar diagram showing the weight distribution of particles finer than 2 mm of the 'Quick till' compared to the 'normal' tills in the Dagali area.

Monkul and Yamamuro (2011): More silt increases the D_{50-sa}/D_{50-si} ratio and the liquefaction potential increases.

Thank you for your attention