Geological analysis of the Kållered quarry and surrounds

Sand & Grus AB Jehander

20 December 2013

By: Björn Sandström and Paul Evins

Assignment ref.: 10187955	Geological analysis of the Kållered quarry and surrounds	
Dated: 20 December 2013	Report	WSP
Revised:		
Representative: Paul Evins	Status: Final	

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1 Executive Summary

This report contains most of the relevant observations made during fieldwork carried out during the period 12/11/2013 – 26/11/2013 in the Kållered quarry and surrounds in accordance with the scope of work described in the WSP proposal, dated 13 September 2013.

A new map and VR model was created over the Kållered quarry and surrounds. Along with structural data collected during this study, the new map shows that the area contains 20 to 50 to 100 m thick layers of mafic rock (gabbro and amphibolite) within a felsic gneissic succession.

The target rock type in the quarry was previously called a diorite, but is likely more mafic and should be classified as a gabbro. Furthermore, a new unit of grey intermediate gneiss has been identified in the western part of the quarry.

Major ductile and brittle structures have a major bearing on the distribution of these sheets and their likelihood of occurrence in the areas of possible quarry expansion. These structures include:

- Ductile folds which may repeat target layers (gabbro) or result in a limited depth for target layers.
- A major N-S trending fault which separates the gabbro layer in the west from amphibolite layers in the east.
- NW trending faults that truncate amphibolite layers and result in changes in amphibolite layer thickness.

The following future work is recommended due to the complex structure and geometry of the gneisses in the quarry:

- Creation of a 3D geological model to better visualize and understand the distribution of target rock types, and estimate resources
- Core drilling to test the interpretations presented in this study at depth and predict rock quality in expansion areas
- Slope stability analysis along the eastern wall of the quarry

2 Introduction

WSP was retained by Sand & Grus AB Jehander for geological mapping of the Kållered quarry and surrounds in Mölndal just south of Göteborg, Sweden (Figs. 1 and 2).

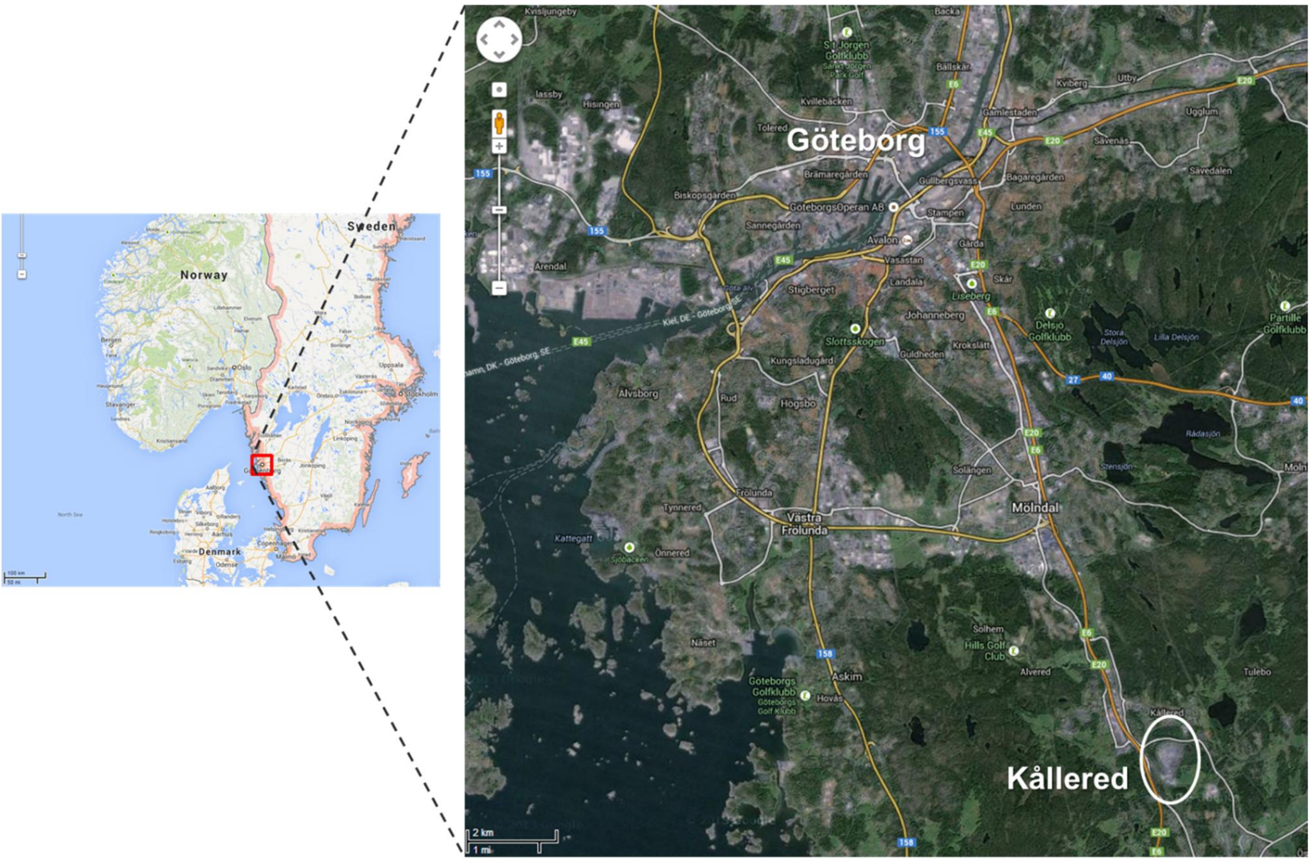

Fig. 1. Location of the Kållered quarry

Fig. 2. View towards SE of the central part of the Kållered quarry.

3 Purpose

The purpose of this mapping exercise is threefold:

- To better understand the distribution of rock types within the quarry and within the confines of Jehander's Kållered tenement
- To target diamond drill holes for exploration under and east of the quarry
- To provide a foundation for a 3D geological model of the quarry and surrounds which can be used for
  - Extraction targeting
  - Resource estimation

In addition, joint data collected in this study may be used as a preliminary dataset for first order slope stability analysis.

The agreed upon scope of work included:

- 58 hours of field mapping
- A written report to include:
  - an outline of the mapping procedures utilized,
  - description of the rock types based on visual observations,
  - a summary of important findings from the mapping area including interpretations and field photographs.
  - recommendations for Phase 2 exploration and expansion investigations

The following additional activities were performed outside of the original scope of this investigation:

- Construction of a virtual reality (VR) model (Appendix 1) from 3D models provided by Johan Lindqvist of Rotoview.

4 Previous Work

The geology of the area was previously mapped and presented in the following reports:

Hersvik D 1999 Berggrundsgeologisk kartering av bergtäktsområdet i Kållered.16 pp.

Ronge B 1998. Berggrundsgeologisk undersökning av området öster om nuvarande bergtäkt I Kållered, Migmatit Geologisk Konsultbyrå AB. 10 pp.

Both studies included ocular geological mapping of surfaces inside and outside the quarry. The map of the area east of the quarry (Ronge 1998) incorporates data from two c. 200 m long trenches and 27 RC drill holes each roughly 30 m long. (Fig. 3).

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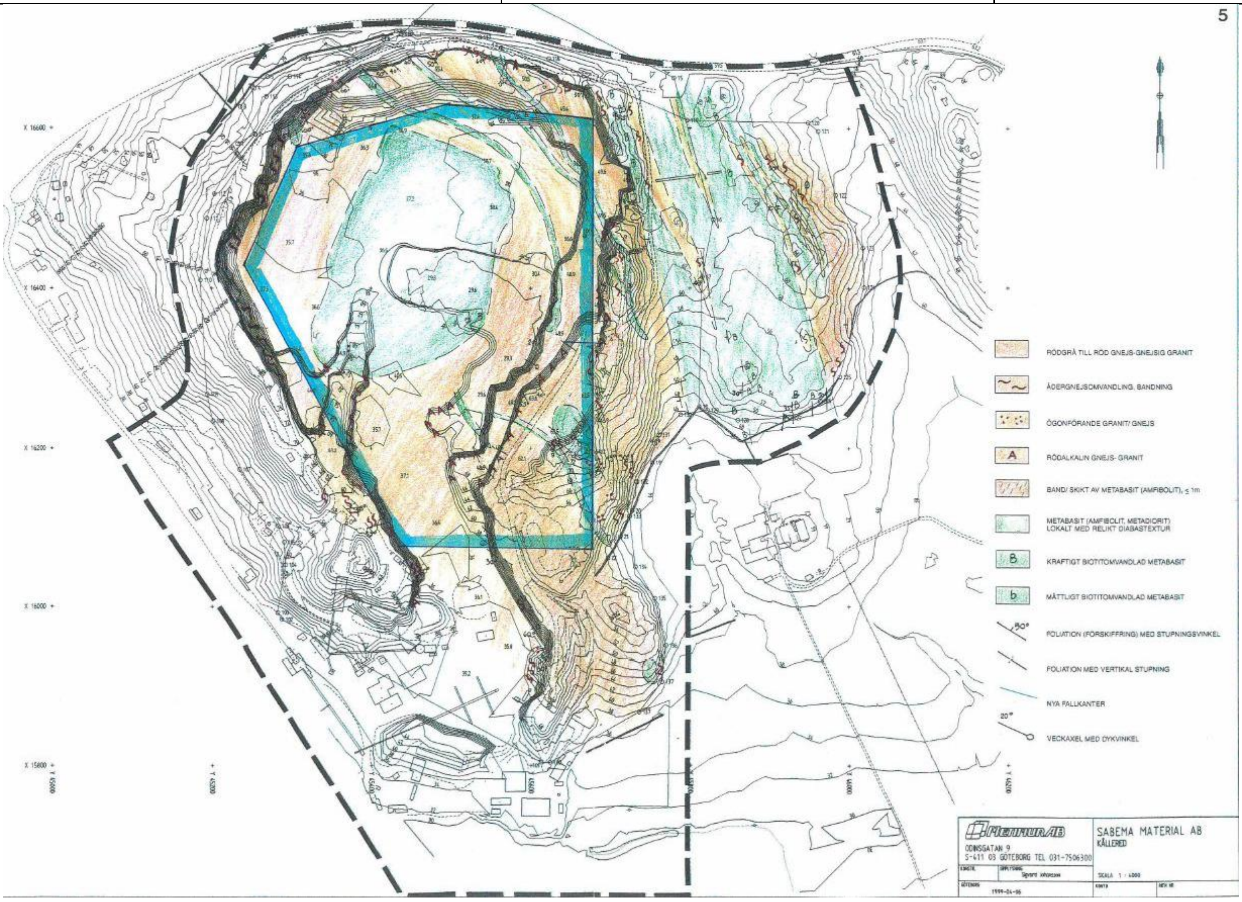

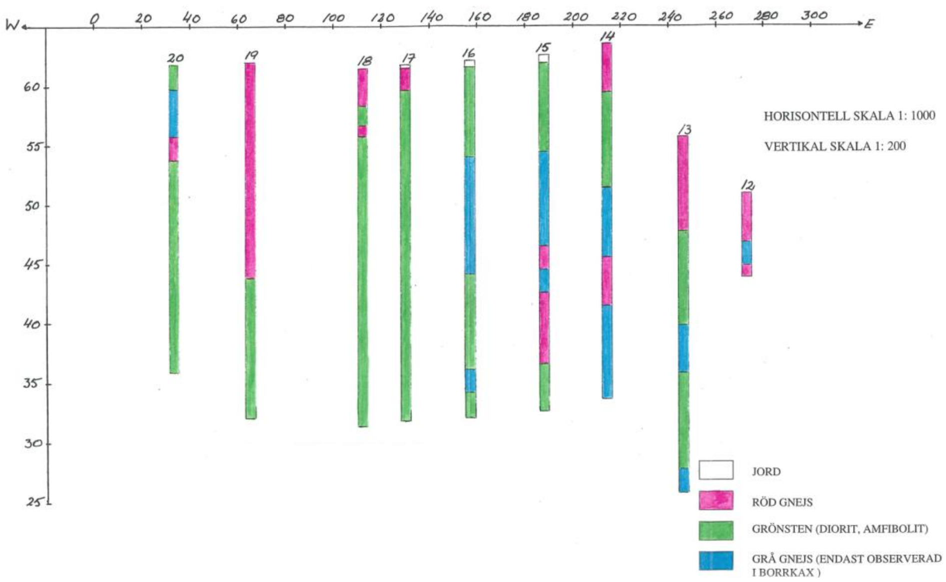

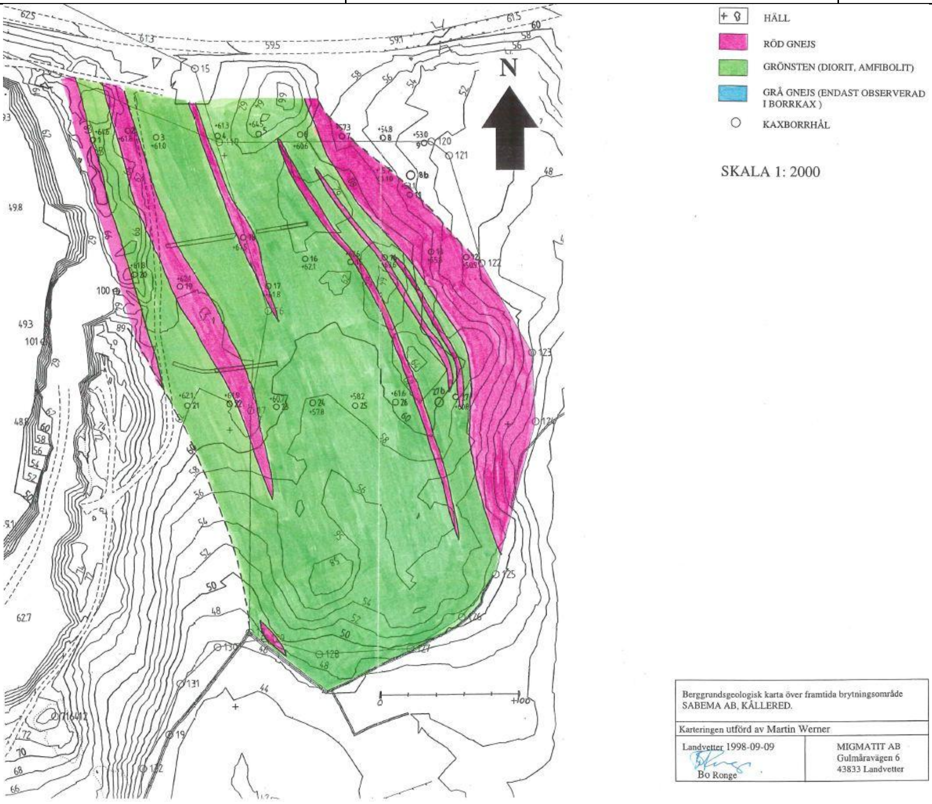

Fig. 3. Top - Previous geological map of the Kållered quarry and surrounds (Hersvik 1999). Centre – example rock chip logs from area east of the quarry (Ronge 1998). Bottom – map of area east of the quarry (Ronge 1998).

5 Methodology, Field Conditions, Participants

The previous maps presented above were georeferenced into a VR workspace which contained the 3D orthophoto model provided by Johan Lindqvist of Rotoview. This VR workspace is a standalone application that allows Sand & Grus AB Jehander to view Rotoview's 3D model on a normal PC without extra software. The maps are hand drawn copies and very few reference points could be used to place them into correct geographic space. Therefore, there may be local errors between like points on the maps and orthophoto. The site was first visited by project manager, Paul Evins and geologist Björn Sandström on 12/11/13 to establish mapping protocols and understand the large scale geological structures in the area. The bulk of field mapping was carried out by Björn Sandström during the period 21/11/2013 – 26/11/2013. Observations were made using standard field equipment and techniques outlined in Coe (2010). Field mapping was based on the VR-model, field observations were hand drawn on printouts from the VR model, then digitized into the VR model (Fig. 4), and then exported to CAD (Fig. 5). Observation locations in the undeveloped eastern area outside the quarry were measured with DGPS with 5 cm accuracy. All field structural measurements were taken with a Silva compass with levelling bubble and clinometer. All field structural measurements are reported as strike-dip according to the right hand rule and are not adjusted for magnetic declination. Data from the previous maps from the quarry (Ronge 1998 and Hersvik 1999) were also incorporated into the map, especially where outcrops have been blasted away.

The following new CAD layers were compiled by Björn Sandström and Maria Trapp and appear on the geological map as digital Appendix 2.

Geology Faults Foliation Rock observations measured by DGPS

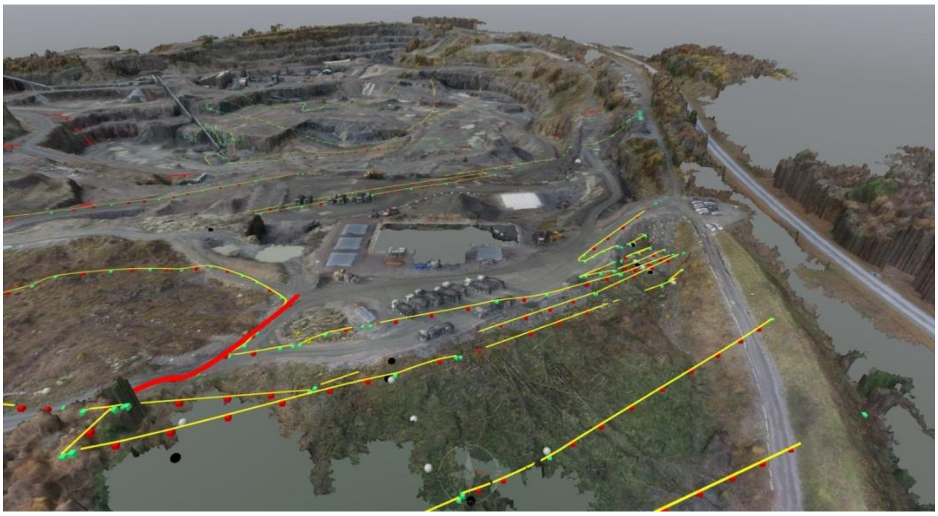

Fig. 4. Screenshot from the VR model used during compilation of the geological map. The black and white spheres in the foreground represent DGPS measurements of rock occurrences (black: amphibolite, white: red-grey gneiss). Yellow lines are interpreted rock contacts and red lines: fauts. View towards NW.

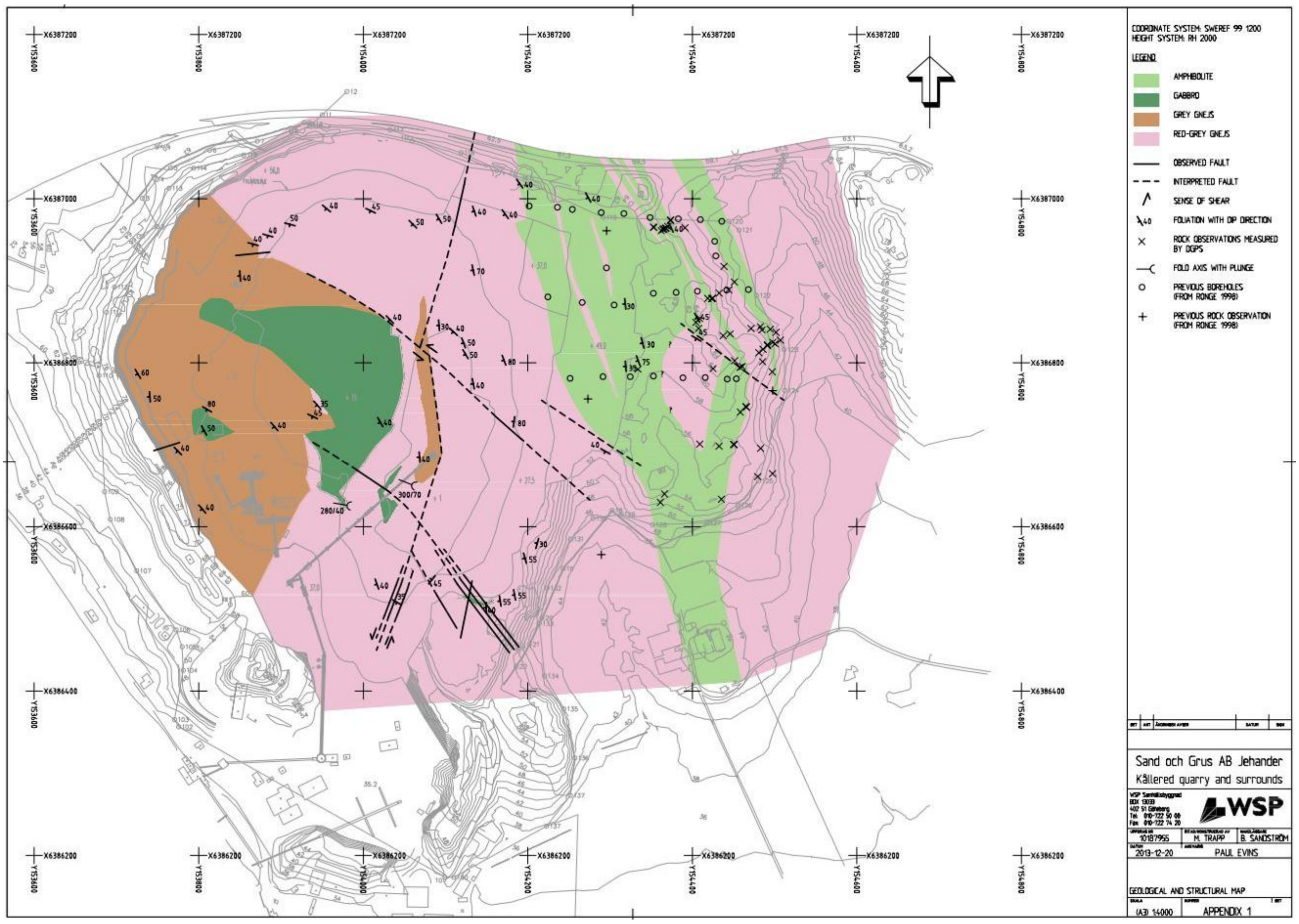

Fig. 5. New geological map of the Kållered quarry and surrounds. The full map is presented in Appendix 1 and electronically in Appendix 2.

6 Results

6.1 Rock Types

The Kållered area is dominated by banded gneiss with igneous protoliths. The main gneiss is a banded red to gray granitic gneiss. Individual gneissic layers range from 1 cm to 10 m depending upon the original size of the protoliths and the amount of strain. In other words, granite veins in shear zones become 1- 10 cm bands while thicker granite veins or areas outside of shear zones show metre-scale banding. The banding is in part caused by and in part deflected into the regional Göta Älv shear zone that runs N-S along highway E6 and dips steeply to the west. A thick sheet of lineated fine- to medium-grained gabbro occupies the central-western part of the currently excavated quarry. This has previously been referred to as a diorite intrusion (Ronge 1988 and Hersvik 1999), but its composition is more mafic and it likely represents a mafic sill. For this study, some rock units were simplified (red and grey gneisses) and others expanded (gabbro and amphibolite). The main rock types mapped in this study are described below.

6.1.1 Grey intermediate gneiss

Grey, fine- to medium-grained gneiss dominates the western part of the quarry (Fig. 7). It is banded on a cm-scale and typically folded. Locally the gneiss is migmatized. The protoliths of this gneiss may be a greywacke. This unit may be the same grey gneiss unit encountered at depth in the drillholes in the eastern expansion area (Ronge 1998). This gneiss and the red-grey gneiss are tectonically interleaved at their contact. In the contact zone between the red-grey and grey gneiss, the two rock types are folded together.

Fig. 7. Grey intermediate gneiss, here highly folded and with bands of red-grey gneiss. The base of the left photo is ca three meters.

6.1.2 Red-grey granitic gneiss

A medium grained, red-grey granitic gneiss dominates the central parts of the investigated area (Fig. 8). The gneiss is tectonically banded and locally highly folded. In the central and eastern part of the quarry, the bands are dm-m scaled. In the western part of the quarry and in faults, it is cm-scale banded. There are four rocktypes that make up the bands in this gneiss. The oldest is the grey intermediate gneiss described above. Locally there are layers of augen gneiss which represent originally sheets of porphyritic granite with up to cm-scale K-feldspar phenocrysts. Together these were intruded by various generations of pink granite and black mafic dykes which have been transposed into the layering. Along some of the fracture zones, particularly the water conductive zones, the gneiss is altered and rust-colored due to precipitation of Fe-oxyhydroxides.

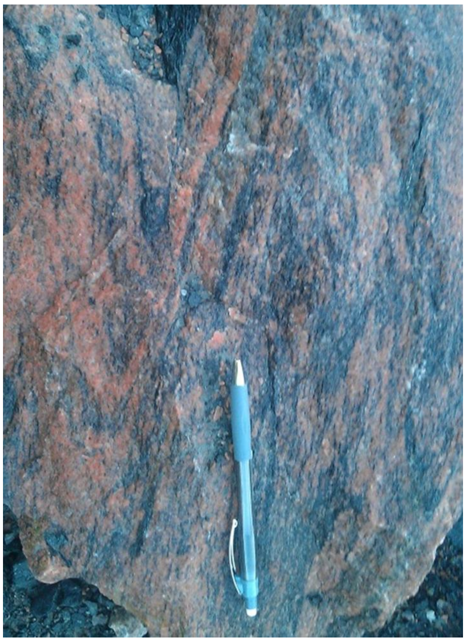

Fig. 8. Red-grey granitic gneiss. Left - meter-scale banded. The base of the left photo is ca three meters. Right – cm scale banded and tightly folded augen gneiss layer

6.1.3 Gabbro

The gabbro that occurs in the central-western part of the quarry is fine- to medium-grained and dark grey. It is equigranular (Fig. 9) to weakly lineated. In the contact zone close to the red-grey and grey gneisses, backveining and some mixing between the different rock types can be seen. The lower contact of the gabbro has been uncovered along the western wall of the lowest excavation level in the quarry. The gabbro is relatively fresh with little later alteration. Normal retrograde metamorphism occurs locally amphiboles retrograded to biotite and biotite to chlorite. Minor occurrences of sulfide are associated with quartz veins in the gabbro near its contacts.

Fig. 9. Gabbro occurrence in the central part of the quarry.

6.1.4 Amphibolite

Amphibolite occurs abundantly in the eastern part quarry. The amphibolite is biotite-rich and shows a distinct foliation following the general foliation pattern of the gneisses in the area (Fig. 10). Locally, minor sulfide mineralization occurs within the amphibolite. It is unclear if the amphibolite is an altered, weathered, more deformed version of the gabbro described above. However, its response to deformation (foliation in the amphibolite vs. lineation in the gabbro) suggest it is not the same rock unit. A couple of geochemical analyses from both rock types could test this hypothesis.

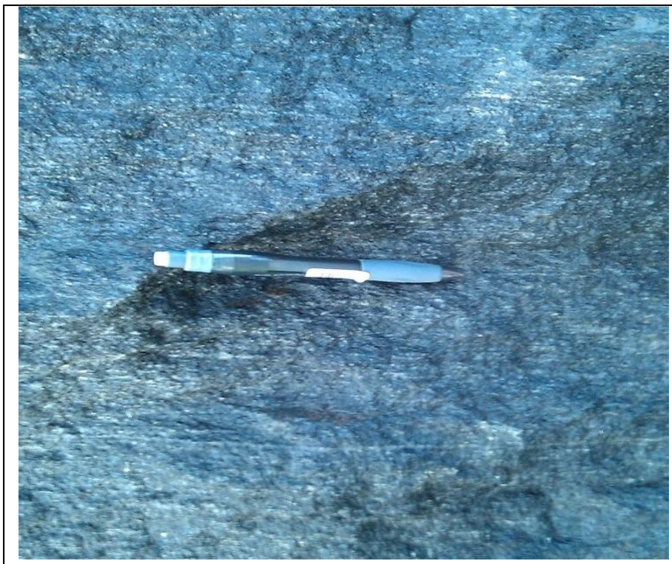

Fig. 10. Biotite rick amphibolite with distinct foliation (left) and together with sulfides (right).

6.2 Distribution of Rock Types (Map Description)

The locations of rock boundaries in plan view on the previous maps are generally correct (Fig. 3). However, the shape of the gabbro body has been revised, mainly due to new information available due to further excavation in the quarry. In particular, the bottom of the gabbro layer was observed along the western wall of the lowest quarry level. Additionally, some of rock boundaries in the eastern part of the area have been adjusted due to new observations. Our mapping has revealed that some of the important rock boundaries are controlled by ductile (folds and shear zones) and brittle (faults) structures. A N-S fault zone runs through the central part of the quarry and divides the geology into eastern and western parts. The rocks in the western part of the quarry are folded by multiple generations making the shapes and contacts of rock units complex (Fig. 11). This makes the rock contacts very difficult to visualize in a 2D-map due to their complexity and moderate dip. The bottom of the gabbro unit is seen at the bottom of the quarry and is interpreted to be a c. 60 m thick sheet within the gneissic layering that dips shallowly to moderately to the west. There is a possibility that it is bowl shaped or repeated by folding which may account for its recurrence further to the west. The rocks in the eastern part of the quarry consist of a c. 50-150 m thick, moderately westward dipping amphibolite with 10 to 20 m thick sheets of red-grey intermediate gneiss.

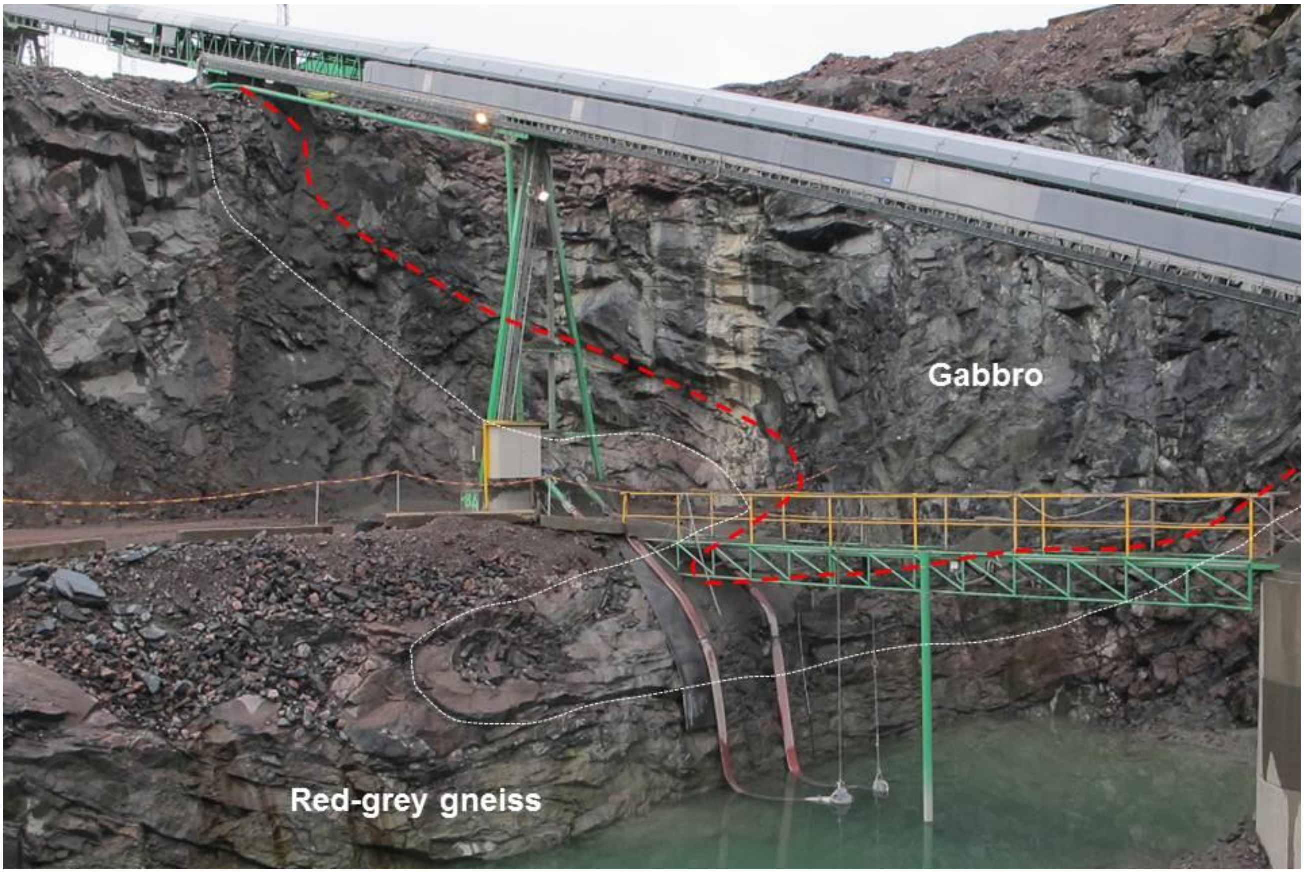

Fig. 11. Isoclinal fold (white line) and complex rock boundaries (red line) between gabbro, red-grey gneiss and grey gneiss.

6.3 Important Structures

6.3.1 Gneissic layering and folding

The gneissic layering in the quarry generally follows a pattern of regional kilometer-scale folding. The quarry is situated on the western limb of an NNW striking anticline with a wavelength of 4-5 km (Fig. 17). Gneissic layering (foliation) in the quarry strikes NNW-SSE and dips moderately (35 to 70°) westward (Appendix 1 and Fig. 8 and Fig. 16). The foliation is undulating and openly folded. In the central parts of the quarry, the foliation is folded into the N-S fault zone. In other areas the foliation changes abruptly across NW trending faults indicating some degree of block rotation (Appendix 1).

Fig. 15. Folded gabbro and red-grey gneiss in the central part of the quarry, the plunge of the fold axis is 280/40°.

Meter-scale to 10 meter-scale folds were observed in the eastern contact zone between the gabbro and the red-gray gneiss (Figs. 11 and 15). Two moderately west plunging (300/70° and 280/40°) fold axis were identified and measured and are presented on the map in Appendix 1. The plunge of this folding generally matches the plunge of macroscopic scale warping (280/40°) of foliation which is best seen where the NNW striking foliation arcs counterclockwise into near parallelism with the northern quarry wall (Figs. 5 and 16). The folding on this scale is complex and the 3D-extent of the rock types controlled by this folding cannot be fully understood without construction of a 3D model.

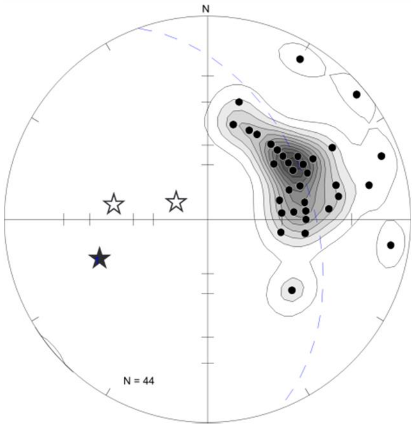

Fig. 16. Lower hemisphere stereographic projection of poles to foliation (dots) in the Kållered quarry and surrounds. Open stars = measured mesoscopic fold axes. Filled star = calculated mesoscopic fold axis.

6.3.2 N-S to NNW trending structures (Göta Älv zone)

The western part of the quarry is situated within the Göta Älv shear zone, a regional NNW trending fault zone (Fig. 17). The zone has both a ductile and brittle history. The main gneissic layering is oriented parallel to this zone reflecting ductile transposition of layering parallel to the zone. The most prominent brittle structure in the quarry is a fault zone seen in the northern wall (Fig. 18). This zone can be traced towards the south across the quarry and to the southern wall where it appears as several more discrete faults spread over a larger area (see map in Fig. 5 and Appendix 1). Movement along this N-S trending fault is responsible for juxtaposing the different rock types found in the western and the eastern part of the quarry (Fig. 19).

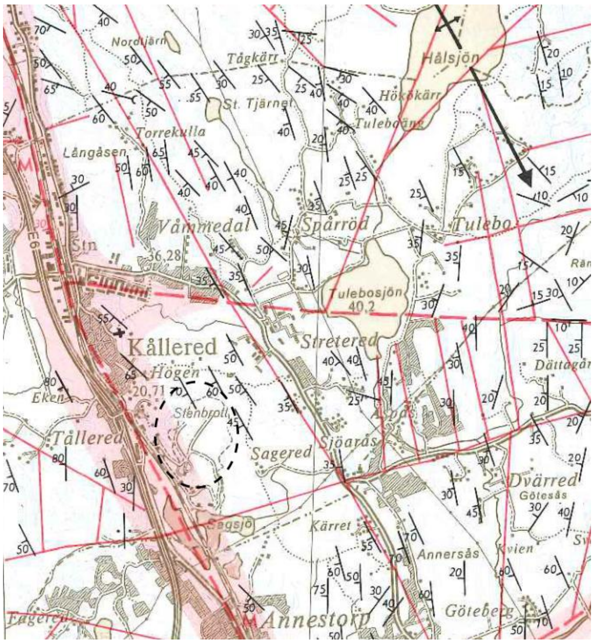

Fig. 17. Tectonic map of the area around the Kållered quarry (marked with circle). The pink field the represents the Göta Älv shear zone. Red lines represent fracture zones (map from SGU 1987). The base of the map is c. 4,5 km.

Fig. 18. N-S trending fault zone in the northern wall of the quarry.

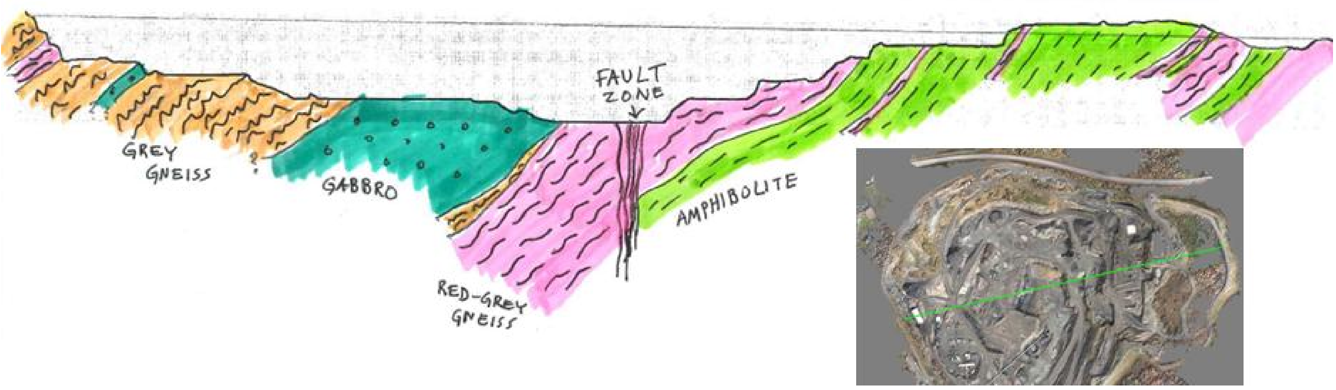

Fig. 19. Schematic WNW-ONO section across the N-S fault zone. For location of the section, see inset figure. Observe that all rock occurrences not are included in the section.

6.3.3 Late NW-trending faults

In the eastern part of the investigated area, abrupt changes in the thickness of red-grey gneiss and amphibolite units imply the presence of NW-trending faults (Fig. 5). Some of these structures were observed on quarry walls, but the ones responsible for the thickness changes have not been observed in the field and need to be confirmed by drilling or trenching.

6.4 Joints

The main foliation planes (Fig. 16) form moderately westward dipping sheets which are a major problem for bench and slope stability along the eastern side of the quarry (Fig. 20 left). Apart from the main foliation planes, there are 3 joint sets present in the quarry: N-S, NW, and E-W trending (Figs. 20 centre and right). All are nearly vertical. The N-S joints are related to the N-S trending faults described in 6.3.2. The NW trending joints are related to the NW-trending faults described in 6.3.3.

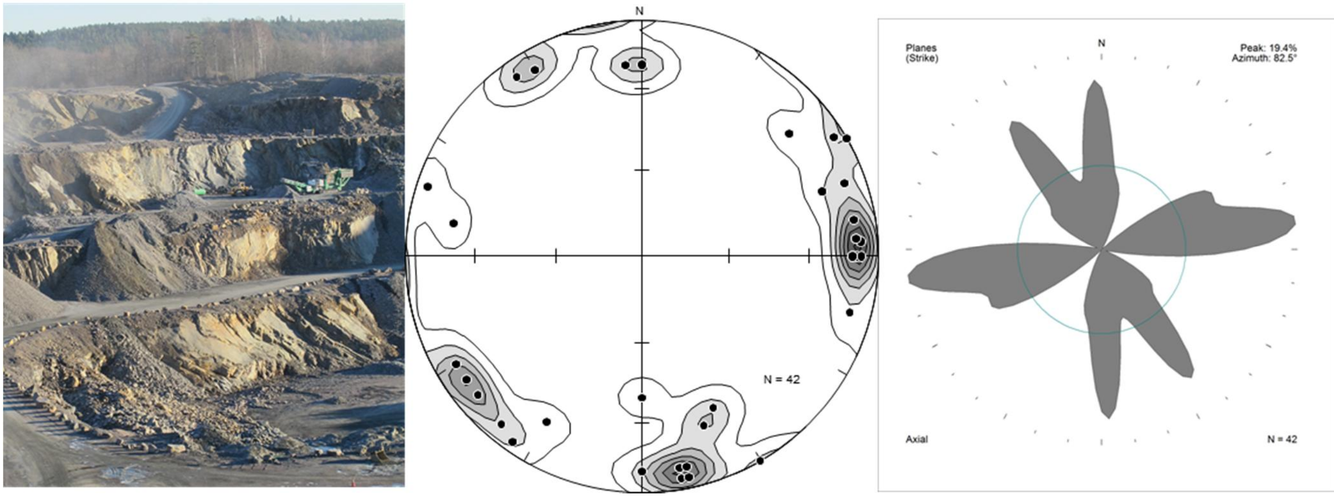

Fig. 20. Left - View towards the SE of unfavorably oriented foliation planes on the eastern wall causing unstable slopes. Centre - Lower hemisphere stereographic projection of poles to joints (dots) in the Kållered quarry and surrounds. Foliation joint planes not included. Right – rose histogram of the strike of joints in plan view.

7 Recommendations

The distribution of the gabbro body in the centre of the quarry and amphibolite layers to the east at the surface have been documented in this report. Furthermore, their thickness and extent at depth have been interpreted based on structural measurements. Remaining uncertainties regarding the interpretation of the geology of the quarry and surrounds include:

1. The shape and spatial extent of the gabbro body at depth in the western-central part of the quarry
2. The distribution of amphibolite and red-grey gneiss at depth in the eastern part of the quarry and the presence of faults within this area.

We recommend core drilling to obtain structural and rock type data from depth and test the above interpretations. In particular, they drill cores may be used to constrain the thickness of the gabbro and amphibolite. Two boreholes (100 and 250 m long) with a low angle (c. 45°) towards the east should be drilled through the amphibolite in the eastern part of the quarry. One of the holes should be orientated so that it penetrates the inferred fault zone in the area. Furthermore, two boreholes (100 m and 200 m long) should be drilled in the central-western part of the quarry with the aim of determining the extent and shape of the gabbro body (Fig. 21).

The drillcore should be mapped by a geologist with experience in the quarry. The geological map or model of the area should then be updated with the data obtained from the boreholes.

Due to the complexity of the rock unit boundaries, the folding and the fault zones, it is recommended that a geological 3D model of the Kållered quarry is constructed. This would increase the understanding of the spatial distribution of the different rock types at depth. In particular, volumes can be created for approximate resource estimation. The model would also enable better and more accurate visualization of the distribution of different rock types and structures for decision-making and planning of future production in the quarry.

A slope stability analysis of the eastern wall of the quarry is suggested if the quarry is to be expanded eastward. The earlier suggestion (Ronge 1998) of excavation of an E-W corridor and then blasting along E-W trending face in that area still applies.

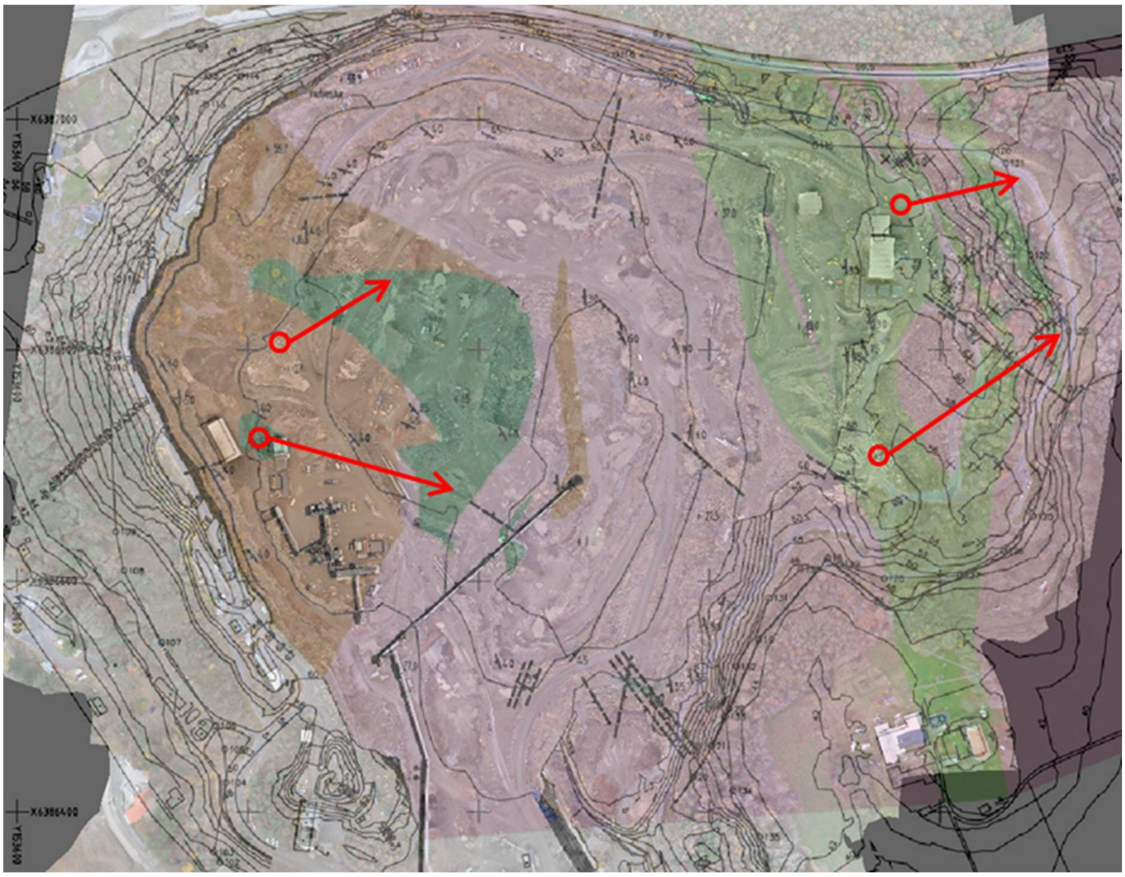

Fig. 18. Suggested location and direction of core drilling (red arrows).

8 References

Coe A.L. (ed.) 2010 Geological field techniques. Wiley-Blackwell. 336 p.

Hersvik D 1999 Berggrundsgeologisk kartering av bergtäktsområdet i Kållered.16 pp.

Ronge B 1998. Berggrundsgeologisk undersökning av området öster om nuvarande bergtäkt I Kållered, Migmatit Geologisk Konsultbyrå AB. 10 pp.

SGU 1978, Tektoniska kartan. Kungsbacka NO. SGU Ser. Af nr 124.

Appendix 1 (electronic) – Geological map (pdf)

Appendix 2 (electronic) – Geological map (dwg)

Appendix 3 (electronic) – VR model

Appendix 4 – Field photographs