P-03-14

Forsmark site investigation

Mapping of unconsolidated Quaternary deposits

Stratigraphical and analytical data

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Sveriges geologiska undersökning (SGU)

Mars 2003

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Keywords: Grain size, mineralogy, calcite, geochemistry, XRD-analysis

Contents

1 Introduction

SKB performs site investigations for location of a deep repository for high level radioactive waste. The site investigations are performed at two sites; Forsmark in the municipality of Östhammar, and Simpevarp in the municipality of Oskarshamn. This document reports the data gained within the activity Mapping of unconsolidated Quaternary deposits at the Forsmark test site shown in Figure 1-1. The analyses were performed according to the activity plan PF 400-02-12 (SKB internal controlling document) following the methods described in the method description for mapping of unconsolidated Quaternary deposits, SKB MD 131.001 (SKB internal controlling document).

Figure 1-1. Location of the area selected for mapping of unconsolidated Quaternary deposits at Forsmark.

2 Objective and scope

The mapping of unconsolidated Quaternary deposits started in mid August 2002 and will be completed by the end of 2003. The investigated area is 7x6 km large (see Figure 1-1). The aim is to describe the aerial distribution of the uppermost unconsolidated deposits, and where possible, the stratigraphical distribution of all Quaternary deposits above the bedrock surface.

Laboratory analyses were carried out on selected samples in order to characterise the chemical and physical properties of mapped unconsolidated deposits. The geochemical and mineralogical analyses will provide information on the origin of the glacial till. Together, the analytical data will be useful for the hydrogeological modelling and for models of the Quaternary evolution of the area.

In this report we present stratigraphical information and results from the analyses of grain size distribution, geochemistry and mineralogy. Additional analytical results and a digital map will be presented in December 2003.

Most of the analysed samples were achieved from borings carried out at the three drill sites established around the cored bore holes KFM01A, KFM02A and KFM03A (Figure 2-1). Drilling and sampling was carried out within other activities but is of central interest for this activity, as they provide information on the total depth and stratigraphical distribution of the Quaternary deposits in the area.

Some of the analysed samples were retrieved during the mapping 2002.

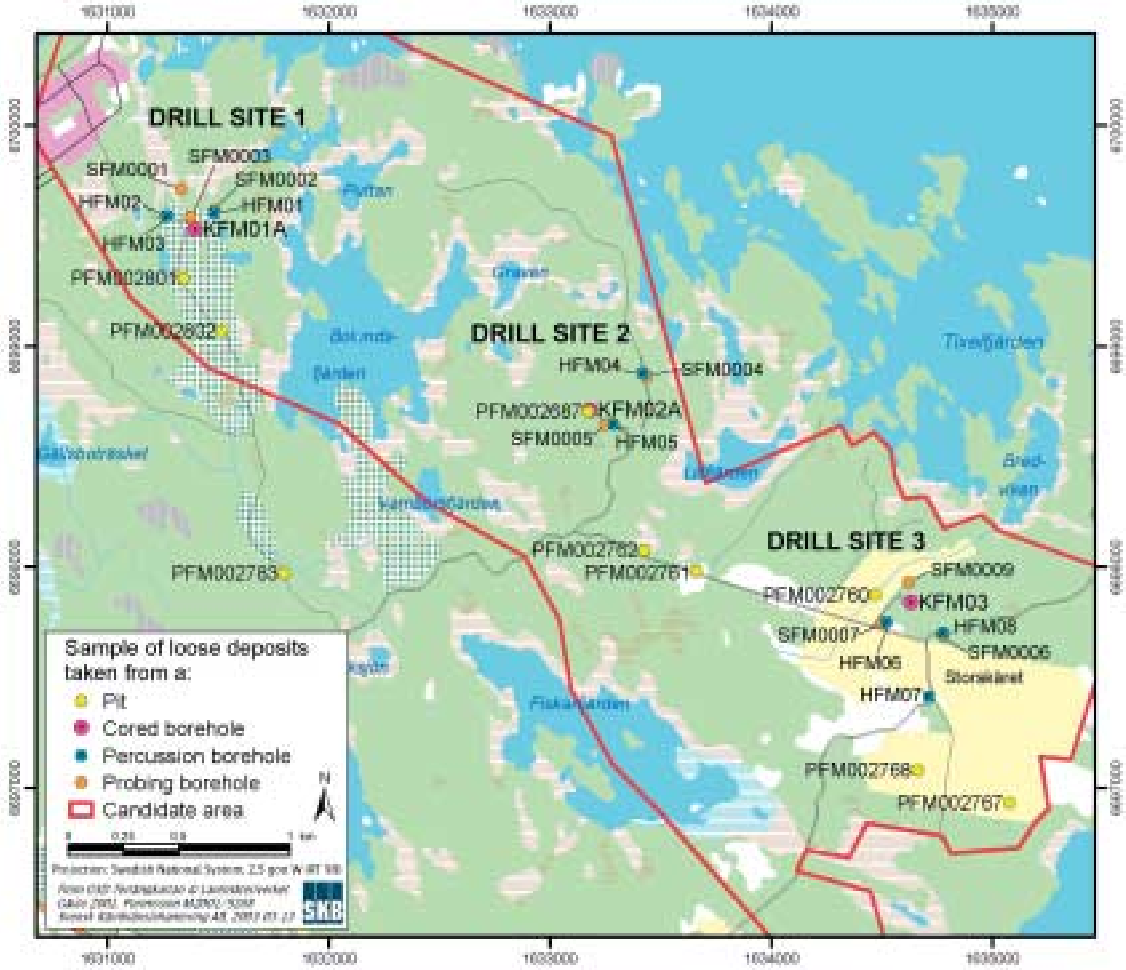

Figure 2-1. *Location of sample sites. No samples were obtained from borehole KFM02A and –03A, since the drillings were performed directly on rock outcrops. (PFM=surface observation point; SFM=probing borehole penetrating unconsolidated deposits; HFM=percussion borehole penetrating hard rock; KFM=cored borehole in hard rock).*

3 Equipment

3.1 Description of equipment

The bulk geochemical composition of the samples was analysed by ICP-MS (Perkin Elmer ELAN 5000). The analytical precision of the geochemical measurements is approximately +/– 5% for most elements. It was, however, not possible to measure Ag, Se, W and Na_2O with a high precision.

The mineralogy was determined with X-ray diffraction analysis (XRD) using a Siemens D5000 (theta-theta) diffractometer (CuKa). The X-ray generator was operating at 50kV and 40 mA. The minerals were identified using the Bruker/Siemens software DIFFRAC^{PLUS} (version 2.2), including the /PDF, 1994/ database for mineral identification. Clay minerals were determined using data from /Brindley and Brown, 1984/.

Grain size analyses were carried out according to /Standardiseringskomissionen i Sverige (SIS), 1992a/ and /Standardiseringskomissionen i Sverige (SIS), 1992b/ (Swedish standard).

4 Execution

This report includes information on the geochemical, mineralogical and textural analyses of unconsolidated Quaternary deposits obtained from surface mapping and drillings in the investigated area (sample sites and location of drill sites are given in Figure 2-1). During drilling, samples were taken every half-metre, when possible. The analyses were performed according to the method description for mapping of unconsolidated Quaternary deposits, SKB MD 131.001 (SKB internal controlling document). The drilling technique is described in the method description for drilling of percussion boreholes, SKB MD 610.003 (SKB internal controlling document). The applied sampling technique is rough and some alteration of the grain size distribution of some samples must therefore be accounted for. For example, some of the samples obtained at drill site 1 consist of silt coated gravel. This grain size composition indicates that these samples were altered during the drilling. The samples obtained from the drillings at drill site 2 and 3 (close to telescopic drilled core borehole KFM02A and KFM03A) appear to be less affected by alteration during drilling.

Fabric analyses were performed at three locations where machine dug pits were available.

4.1 Data handling

The observation points from the surface mapping of Quaternary deposits are assigned so called PFM numbers, whereas the drill sites are recognized by respectively SFM, HFM or KFM numbers, depending on the drilling technique applied (SFM=probing borehole penetrating the soil layer, HFM=percussion borehole in hard rock, KFM=cored borehole in hard rock).

The location of stratigraphical point observations at the surface was determined with GPS and stored in SICADA (Field note Forsmark 39). The geological information connected to the PFM, HFM, SFM and KFM numbers were stored in a data base for mapping of unconsolidated Quaternary deposits at the Geological Survey of Sweden (Jorddagboken, Version 5.4.3). The data were subsequently exported to SICADA (Field note Forsmark 39).

The following data have been exported to SICADA.

- Stratigraphical information from boreholes SFM01-08, HFM01-08 and KFM01A.
- Data from fabric measurements.
- Results from grain size and $CaCO_3$ analyses.
- Results from bulk geochemical analyses.
- Quantitative distribution of minerals in material < 2 mm (XRD analytical data).

The following diagrams are stored in the SKB file archive:.

- Diagrams showing the results from grain size analyses (47 analyses).
- X-Ray diffractograms (13 analyses) from qualitative XRD-analyses of the clay fraction (material < 2 µm).

4.2 Analyses

The samples from the drillings were characterised in the laboratory. HCl was dropped on all samples in order to find out if calcite is present. Some samples were selected for additional analyses. Not analysed samples and dried residual of analysed samples are stored at SKB (Forsmark).

Quantitative XRD analysis was carried out at SGU in Uppsala according to /Srodon et al, 2001/. Eight till samples were analysed on non-oriented material < 2 mm. X-ray diffractograms are given in Appendix 1. ZnO was used as an internal standard. The standard and the samples were ground together with alcohol. The data is stored in the SKB SICADA database under filed note Forsmark 39.

Qualitative XRD-analyses of clay mineralogy composition (material < 2 µm) of oriented samples were made at SGU in Uppsala on four till samples according to /Drever, 1973/. The fraction < 2 µm was collected during sedimentation in settling tubes. The analytical results are shown in X-Ray diffractograms in Appendix 2. The diagrams are stored in the SKB file archive under filed note Forsmark 39 and also given in Appendix 2.

Bulk geochemical analyses were carried out on parallel till samples from the same eight locations sampled for XRD-analysis. Two grain size fractions, < 63 µm and < 2 mm, respectively, were analysed with ICP-MS (at SGU in Uppsala), after leaching with 7M HNO_3. The analytical data is stored in the SKB SICADA database under filed note Forsmark 39.

Grain size analyses on material < 20 mm, were carried out on 47 samples at SWECO, Geolab in Stockholm. The grain size distribution of coarse material (20–0.063 mm) was determined by sieving and finer material (< 0.063 mm) with a hydrometer. The content of $CaCO_3$ was determined (SWECO, Geolab) on the same 47 samples (grain sizes < 0,063 mm) using Passons apparatus /Talme and Almén, 1975/. Colour of the 47 samples was determined according to /Munsell, 1994/. The analytical data is stored in the SKB SICADA database under field note Forsmark 39. Grain size distribution diagrams are stored in the SKB file archive under field note Forsmark 39.

Fabric analyses were performed in glacial till at three sites according to /Dowdeswell and Sharp, 1986/. A horizontal surface was first prepared a few decimetres below the ground surface. Gravel and larger particles were measured. The relationship between the *a* and *b* axis was always larger than 3/2. The direction and dip of the *a* axis was measured on at least 25 particles at each site. The data is stored in the SKB SICADA database under field note Forsmark 39.

5 Results

5.1 Stratigraphical distribution of glacial till

The Forsmark area is flat and glacial till is the most common Quaternary deposit. The ground water table is high and the area is therefore rich in lakes and wet lands. So far the present mapping confirms most of what is shown in the earlier maps /Persson 1985, 1986/. The new mapping, however, provides more information regarding the distribution of water laid sediments, peat and exposed bedrock.

Sandy till is the most common deposit at the mapping depth (50 cm) in the area investigated during 2002. However, the fields and pasture-grounds around drill site 3 and Storskäret (Figure 2-1) are dominated by clayey till.

Three till units were defined in the samples from the drillings at drill site 1 (Figure 2-1). From ground surface: gravely till (unit1), sandy till (unit 2) and silty till (unit 3). The first till type (unit 1) seems to be uncommon in the investigated area. Tills rich in sand, silt and clay are the three most common till types. A till rich in silt is overlaying the bedrock surface at both drill site 1 and 2 (Figure 2-1). However, it is not known to what extent that silty till superpose the bedrock of the area under investigation. In connection with the building of reactor 3 (Forsmark) /Agrell and Björnbom, 1977/ observed a silty till at the same stratigraphical position as mentioned above.

At drill site 3 (Figure 2-1), clayey till dominates from the ground surface down to the bedrock. In borehole SFM0008, however, there is a silty till below the clayey till. Two of the samples analysed, one from HFM07 and one from SFM0008, have clay contents > 15% (i.e. clay till).

It has been suggested that the clayey till, where it occurs, always lays directly on the bedrock /Persson, 1985/. However, the result from SFM0008 shows that silty and sandy till underlay the clayey till, at least at that site.

The clayey till may cover larger areas than suggested by the map made by /Persson, 1985/, which is indicated by the presence of clayey till in HFM05, at drill site 2 (Figure 2-1). Below that clayey, a sandy till is directly overlaying the bedrock.

The results presented above, suggest that the stratigraphical distribution of glacial till is complicated. The forthcoming geophysical and stratigraphical investigations will hopefully give more conclusive information.

The knowledge about the total thickness of the Quaternary deposits in the area is at present not complete. The earlier mapping shows that the clayey till in average is thicker than the sandy and silty till /Persson, 1985/. Deposits other than till are often thin /Persson, 1985/.

Borings at drill site 1 showed that up to 12 m of till covers the bedrock. There is exposed bedrock only a few tenths of metres from the boring sites. This implies that the bedrock surface is more undulating than what the relatively flat ground surface suggests. In borehole HFM07, at drill site 3, the total thickness of clayey till is almost 7 m. In borehole SFM0004, at drill site 2, there is more than 5 m of till above the bedrock.

5.2 Mineralogy and geochemistry

Quantitative XRD analyses were carried out on eight samples (Appendix 1). There are only small variations in the contents of most silicate minerals. The samples contain almost 40% of quartz, which is similar to most of the bedrock in the investigated area. There is a relatively high content of hornblende in the two samples from borehole HFM02. The hornblende may emanate from an occurrence of Gabbro c. 1 km west of HFM02. Calcite is present in all samples, which is confirmed by the analyses with Passons apparatus (see below). The calcite emanates from Ordovician limestone present at the sea bottom north of the area.

Qualitative X-ray diffraction (XRD) analyses were carried out on four till samples (Appendix 2) and Illite turns out to be the most common clay mineral in all four samples. The results show that the illite/chlorite ratio is higher in the two clayey tills (samples HFM07_1 and HFM08_2) compared to the silty-sandy tills (samples SFM0004_1 and HFM05_2). The XRD-data will be fully evaluated during the autumn 2003 when also supplementary data are available.

Geochemical analyses of HNO_3-leachable elements demonstrate a positive correlation between the clay content and the contents of most elements in the eight samples analysed so far. The elements are probably leached out more effectively from the fine grained material. The sample from borehole HFM04 has much higher contents of several trace elements (Cu, Mo, W and Sn) compared to the other samples analysed. It is not known if the enrichment is caused by natural processes or by contamination from the drilling equipment. Also the geochemical data will be fully evaluated during the autumn 2003 when more data are available.

The HCl-test shows that all till samples contains calcite. The results from analyses with Passons apparatus illustrate that some till samples has a calcite content exceeding 30%. Sample PFM002783_2 is a glacial clay with a $CaCO_3$ content of 25%. Sample PFM002783_1 contains gravel and is the only sample where $CaCO_3$ is almost absent. This gravel lies on the top of the glacial clay (PFM002783_2) and has been redoposited from the neighbouring tills by wave washing. The calcite was probably dissolved during that process.

The fabric results from PFM002687 indicate a deposition from north-west, whereas the results from PFM002801 and PFM002802 indicate ice movements from the north and the north-east, respectively. These results indicate that the till in the area has been deposited during different phases of the glaciation. The results from measurements of glacial striae do not show any indication of an ice movement from north-east. More fabric data will be available after the summer 2003.

6 References

Agrell H, Björnbom S, 1977. Blå Morän vid Forsmarks Kärnkraftverk. SGU central archive F11A:C3 ME:paper.

Brindley G W, Brown G, 1984. Crystal structures of clay minerals and their X-ray identification. – Mineralogical Society, Monograph no. 5, Mineralogical Society, 41 Queen's Gate, London SW7 5HR.

Drever S I, 1973. The preparation of oriented clay mineral specimens for X-ray diffraction analysis by a filter-membrane peel technique. – Am. Miner., 58, 553–554.

Dowdeswell J A, Sharp M J, 1986. Characterization of pebble fabrics in modern terrestrial glacigenic sediments. Sedimentology 33, 699–710.

Munsell Soil Color Charts, 1994. Macbeth Division of Kollmorgan Insruments Corporation, New Widsor.

PDF, 1994. Powder diffraction file computer data base. Set 1–43. International Centre for Diffraction Data, Park Lane, Swartmore, PA, USA.

Persson Ch, 1985. The Quaternary map Östhammar NO. Swedish Geological Survey, Ae 73.

Persson Ch, 1986. The Quaternary map Österlövsta SO/Grundkallen SV. Swedish Geological Survey, Ae 76.

Srodon J, Drits V A, McCarty D K, Hsieh J C C, Eberl D D, 2001. Quantitative X-ray diffraction analysis of clay-bearing rocks from random preparations. Clay and Clay Minerals 49, 514–528.

Standardiseringskomissionen i Sverige (SIS), 1992a. Geotekniska provtagnings-metoder – Kornfördelning – Siktning. Svensk Standard, SS 02 71 23, 4 pp.

Standardiseringskomissionen i Sverige (SIS), 1992b. Geotekniska provtagnings-metoder – Kornfördelning – Sedimentering, hydrometermetoden. Svensk Standard, SS02 71 24, 7 pp.

Talme O, Almén K-E, 1975. Jordartsanalys. Laboratorieanvisningar, del 1. Department of Quaternary Research, Stockholm University, 133 pp

Appendix 1

Quantitative X-ray analyses of till material < 2mm

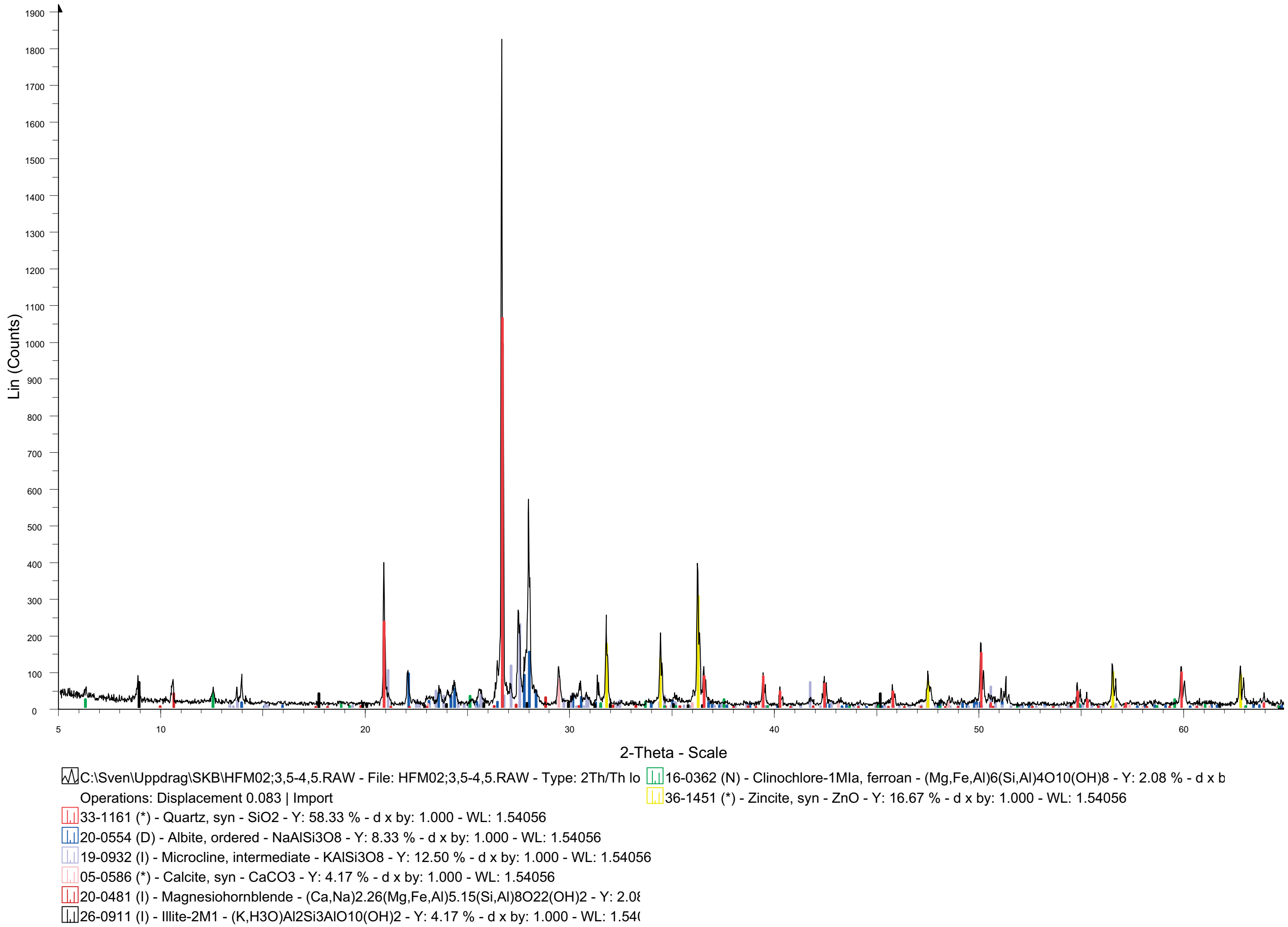

***Figure A1-1.** X-ray diffractogram of material < 2 mm (HFM02_2 (3,5–4,5m). The internal standard (ZnO) is marked with yellow.*

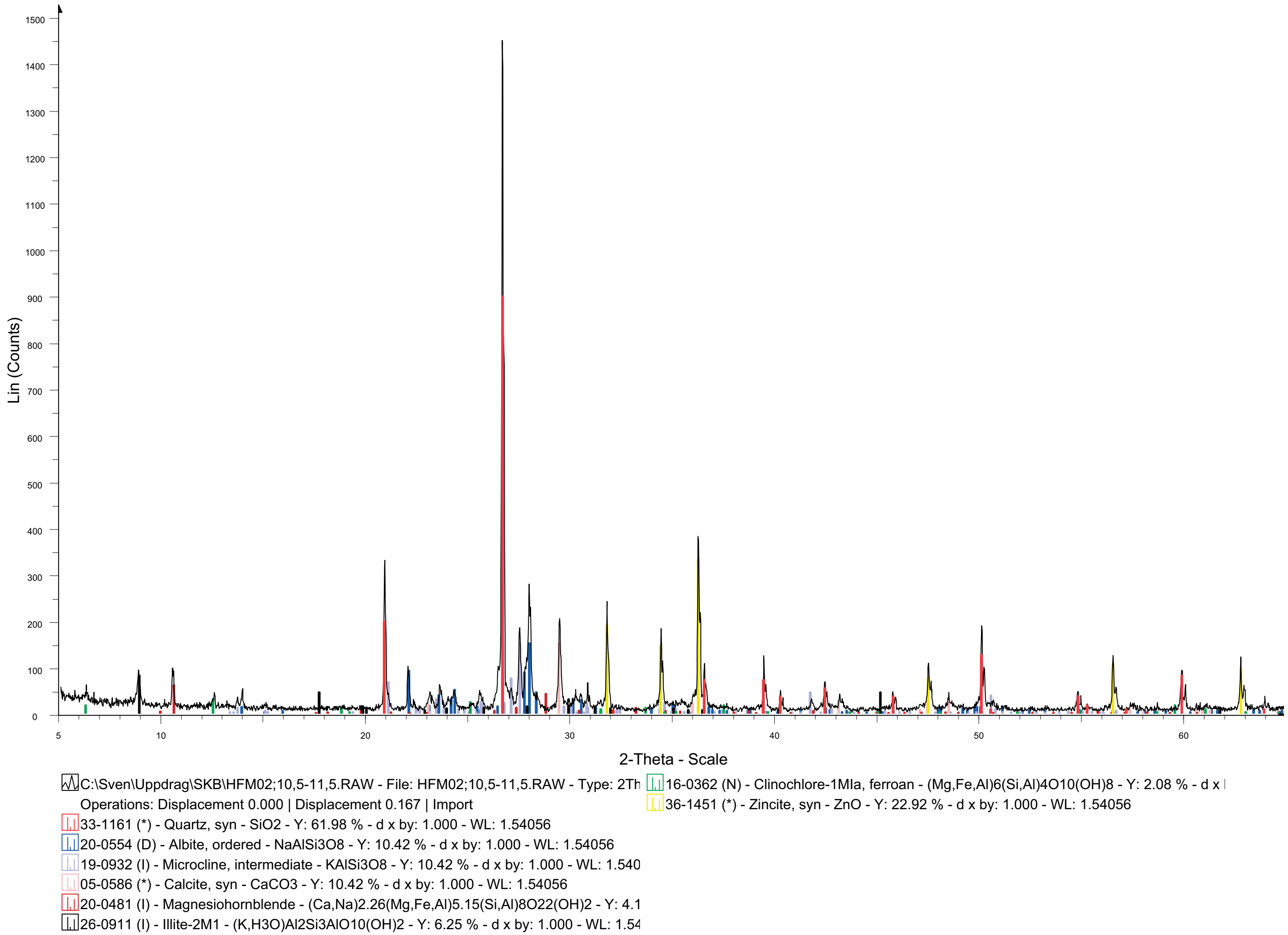

Figure A1-2. *X-ray diffractogram of material < 2 mm (HFM02_3, 10.5–11.5 m). The internal standard (ZnO) is marked with yellow.*

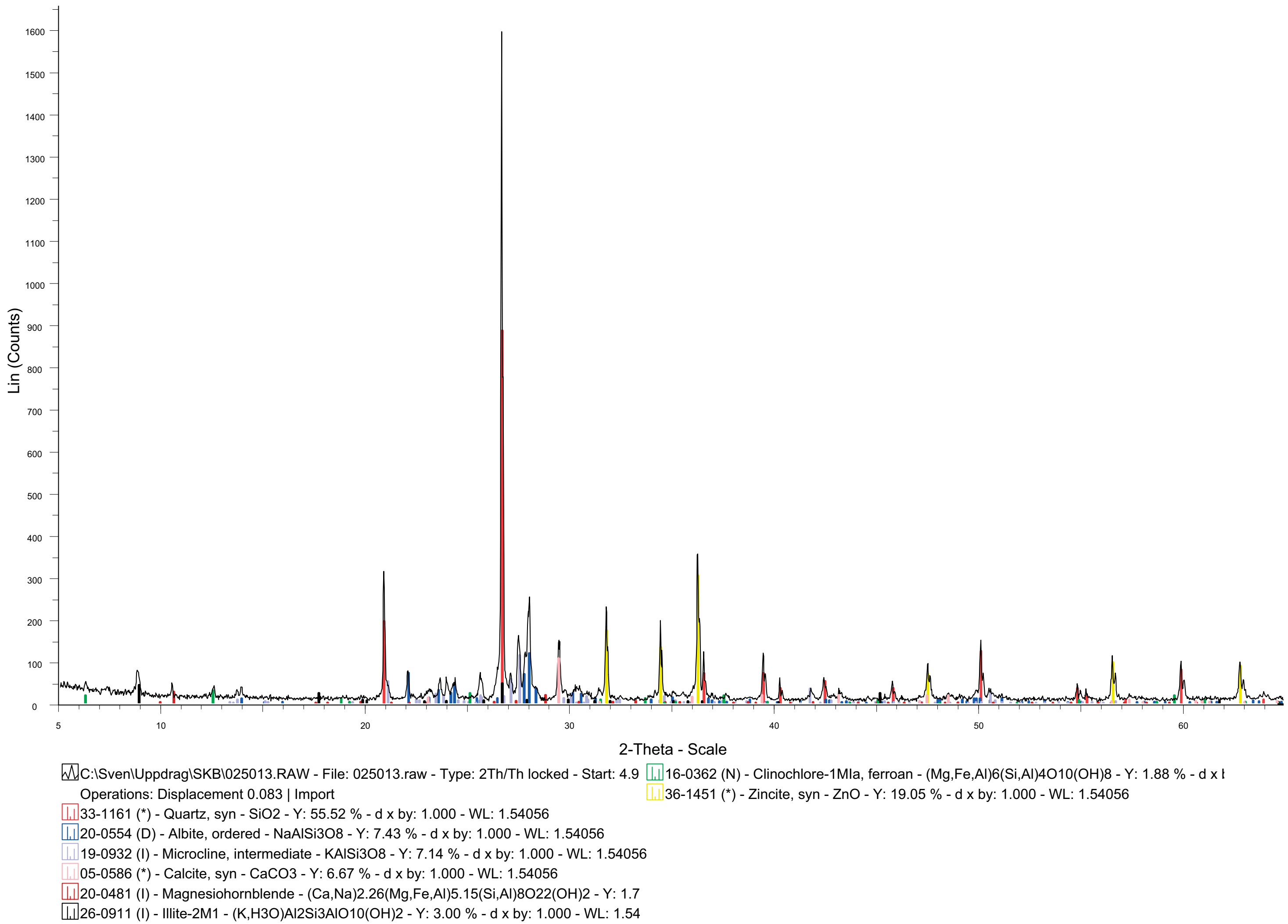

Figure A1-3. *X-ray diffractogram of material < 2 mm (HFM04_1, 0.5–0.85 m). The internal standard (ZnO) is marked with yellow.*

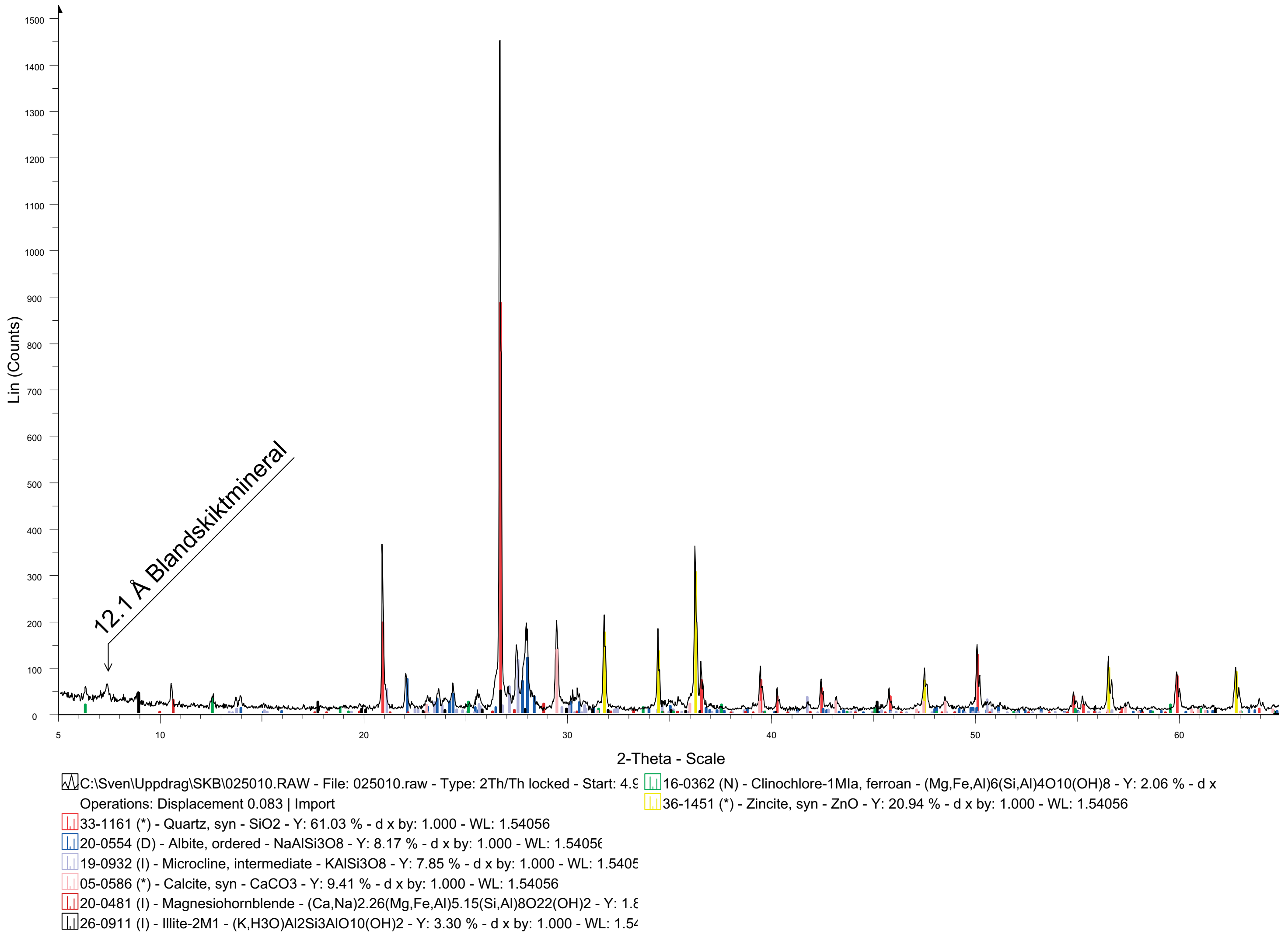

Figure A1-4. *X-ray diffractogram of material < 2 mm (PFM002687_1, 0.5 m). The internal standard (ZnO) is marked with yellow.*

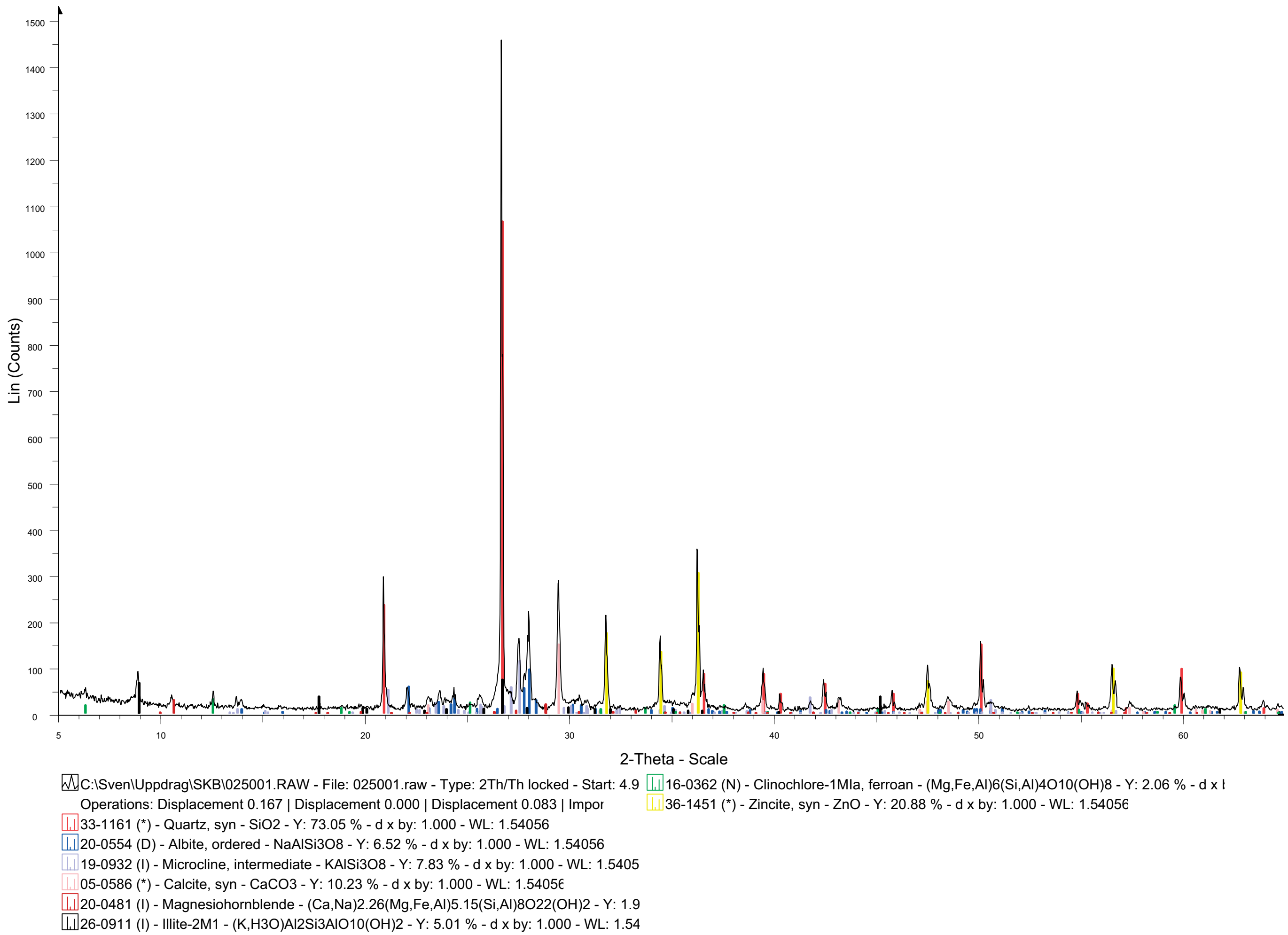

Figure A1-5. *X-ray diffractogram of material < 2 mm (PFM002760_1, 1 m). The internal standard (ZnO) is marked with yellow.*

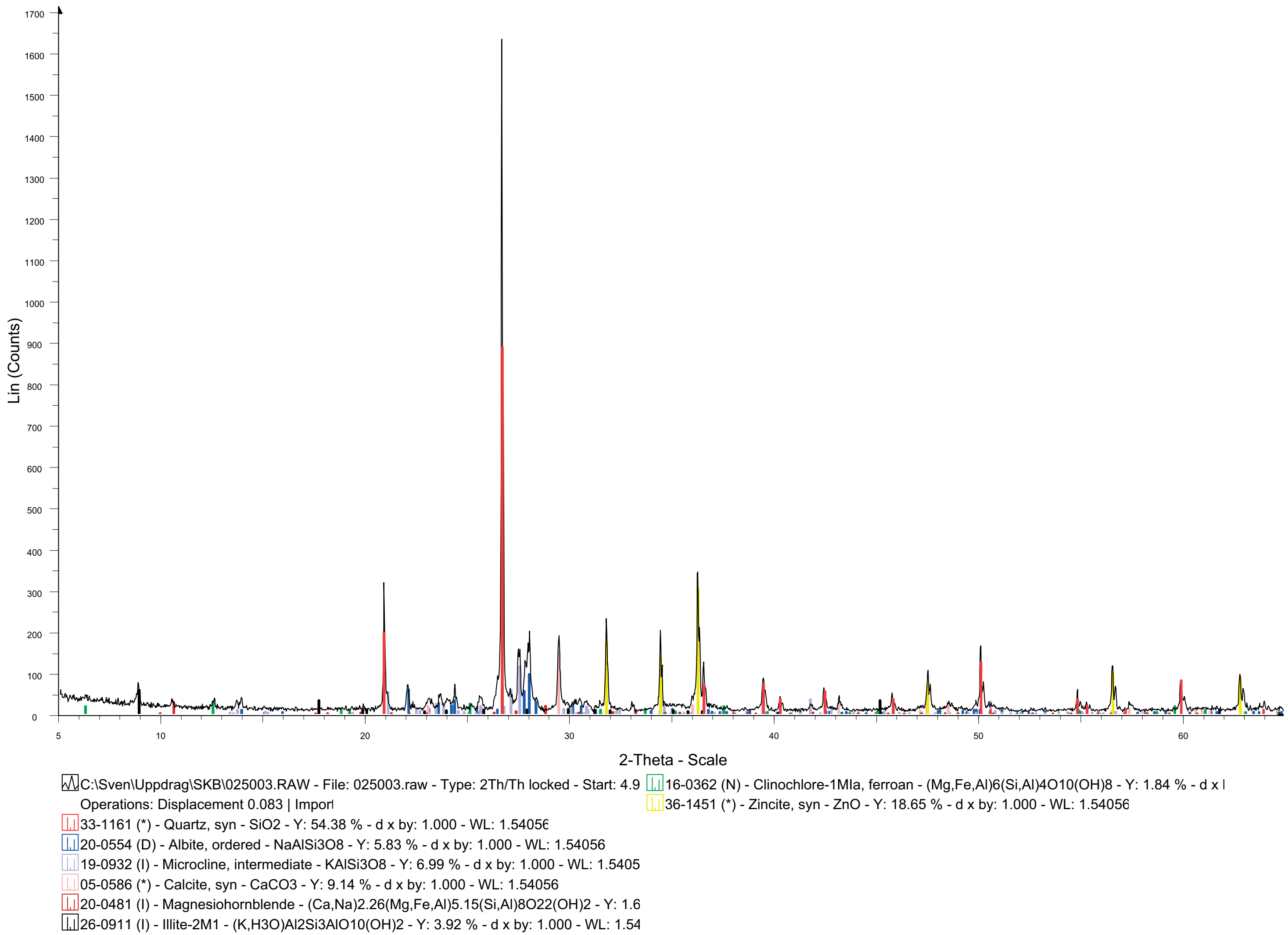

Figure A1-6. *X-ray diffractogram of material < 2 mm (PFM002762_1, 0.5 m). The internal standard (ZnO) is marked with yellow.*

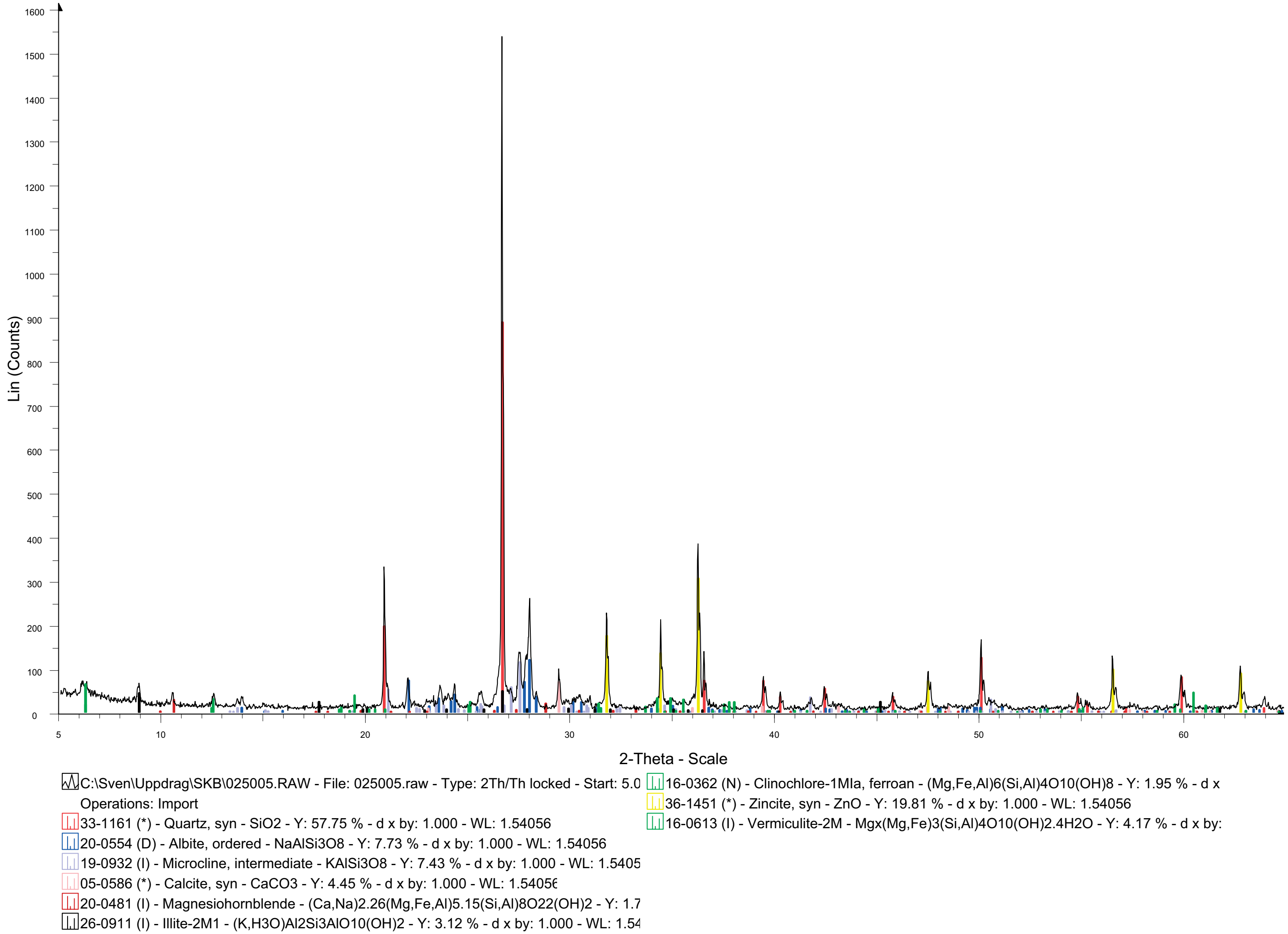

Figure A1-7. *X-ray diffractogram of material < 2 mm (PFM002768_1, 1 m). The internal standard (ZnO) is marked with yellow.*

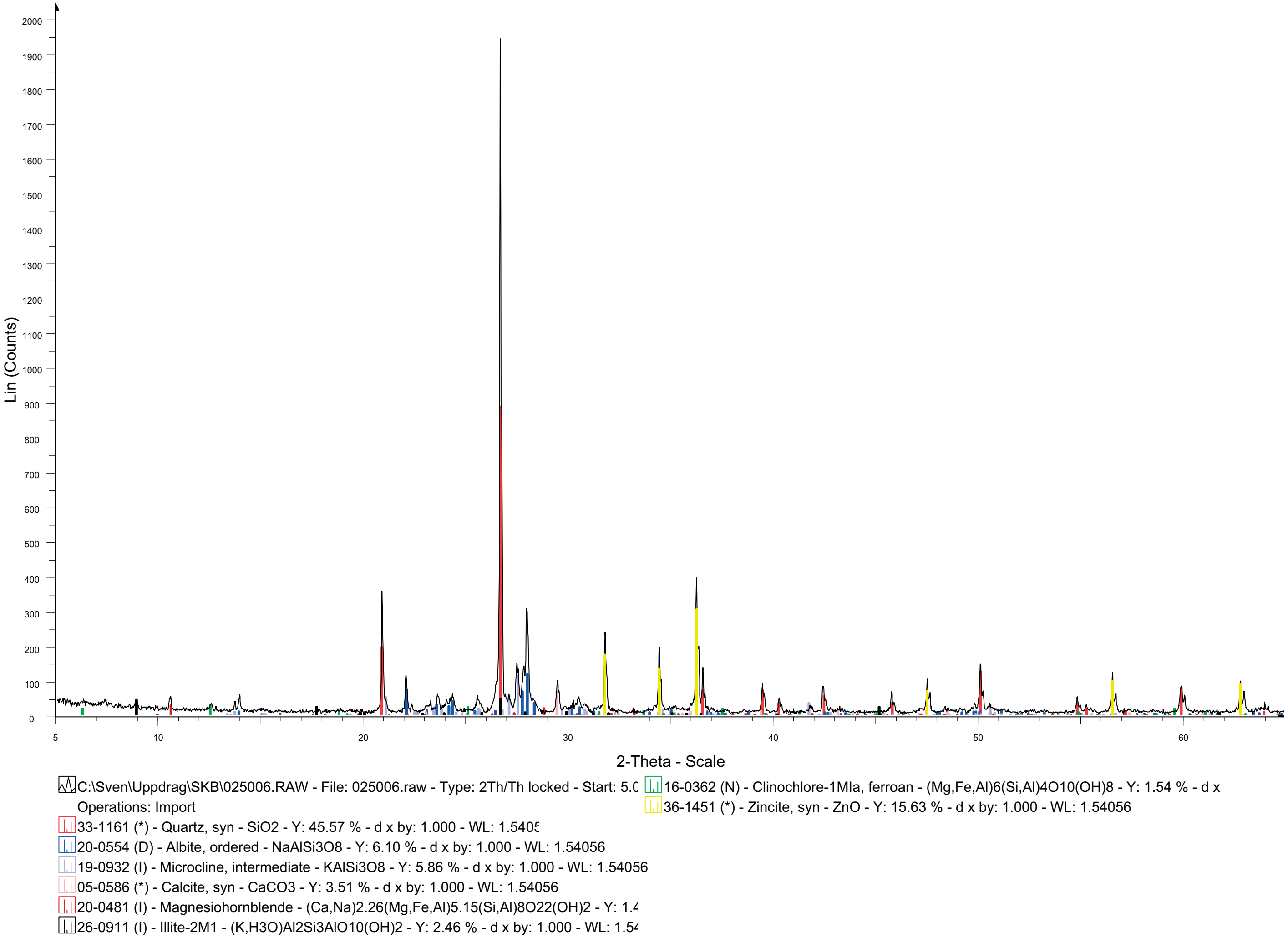

Figure A1-8. *X-ray diffractogram of material < 2 mm (PFM002801_1, 0,4 m). The internal standard (ZnO) is marked with yellow.*

Appendix 2

Qualitative analyses of clay minerals.

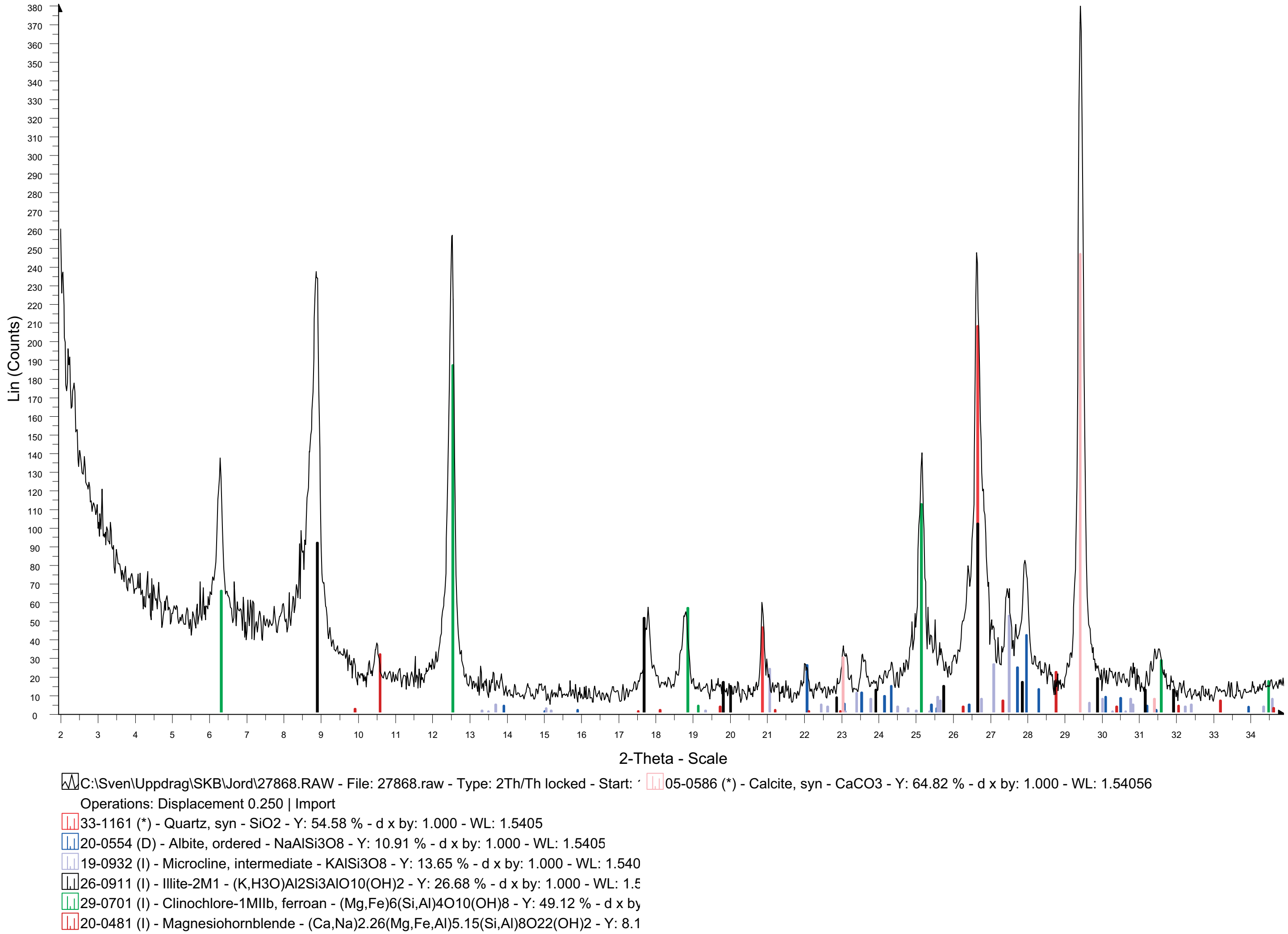

Figure A2-1. *X-ray diffractogram showing the distribution of clay minerals (HFM05_2, 3.–3.5 m).*

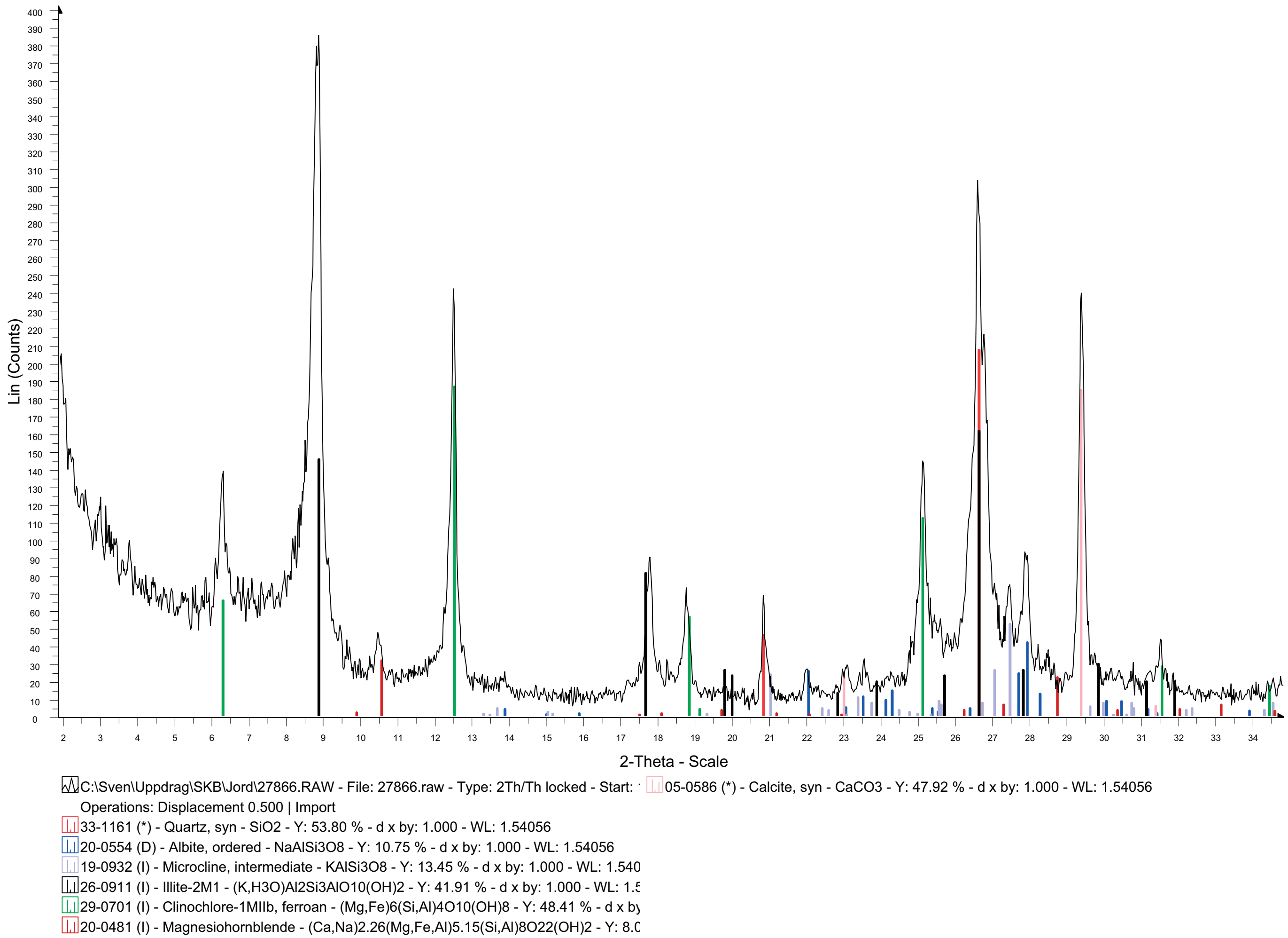

Figure A2-2. *X-ray diffractogram showing the distribution of clay minerals (HFM07_1, 1.5 m).*

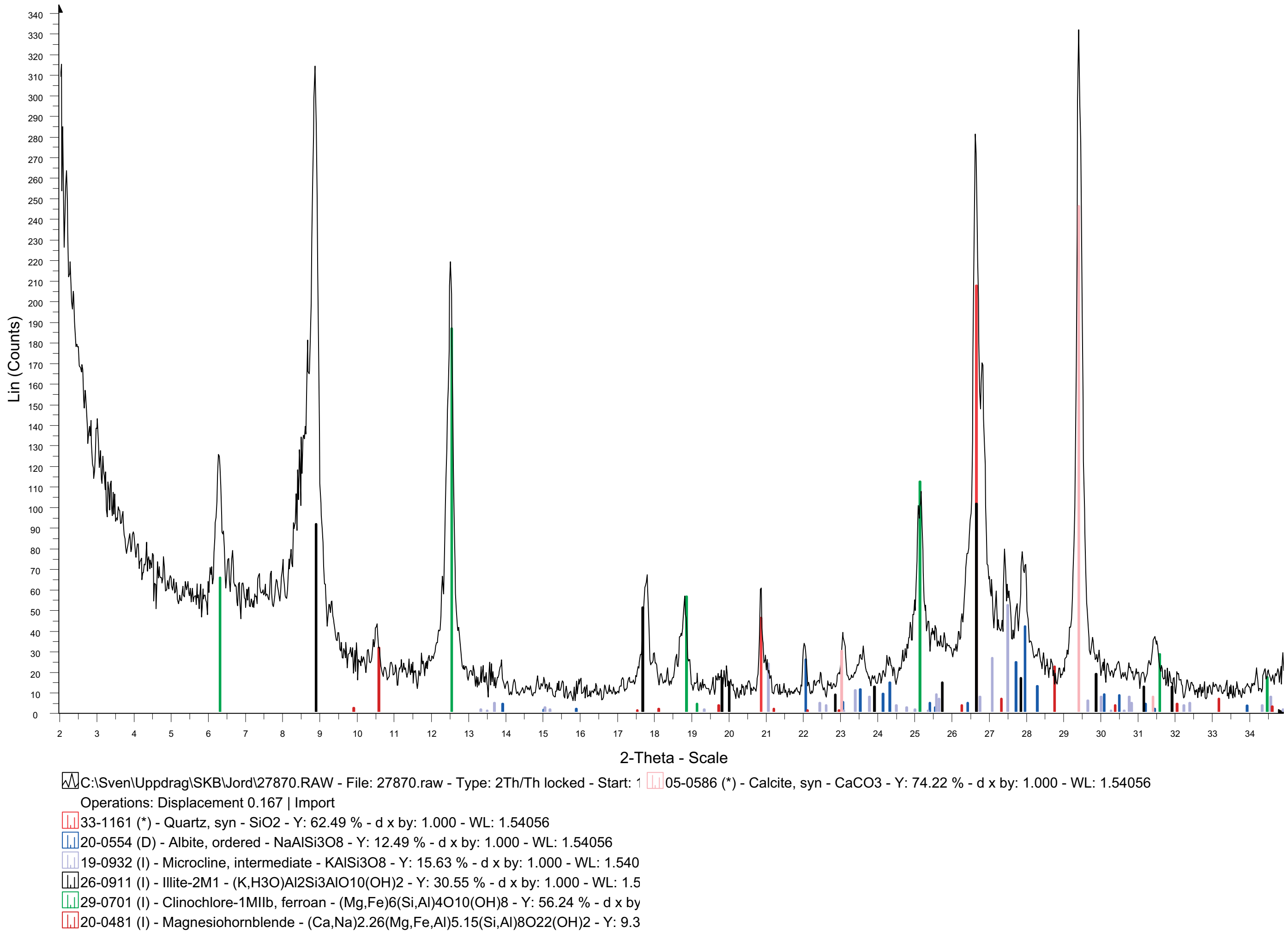

Figure A2-3. *X-ray diffractogram showing the distribution of clay minerals (HFM08_2, 4.5 m).*

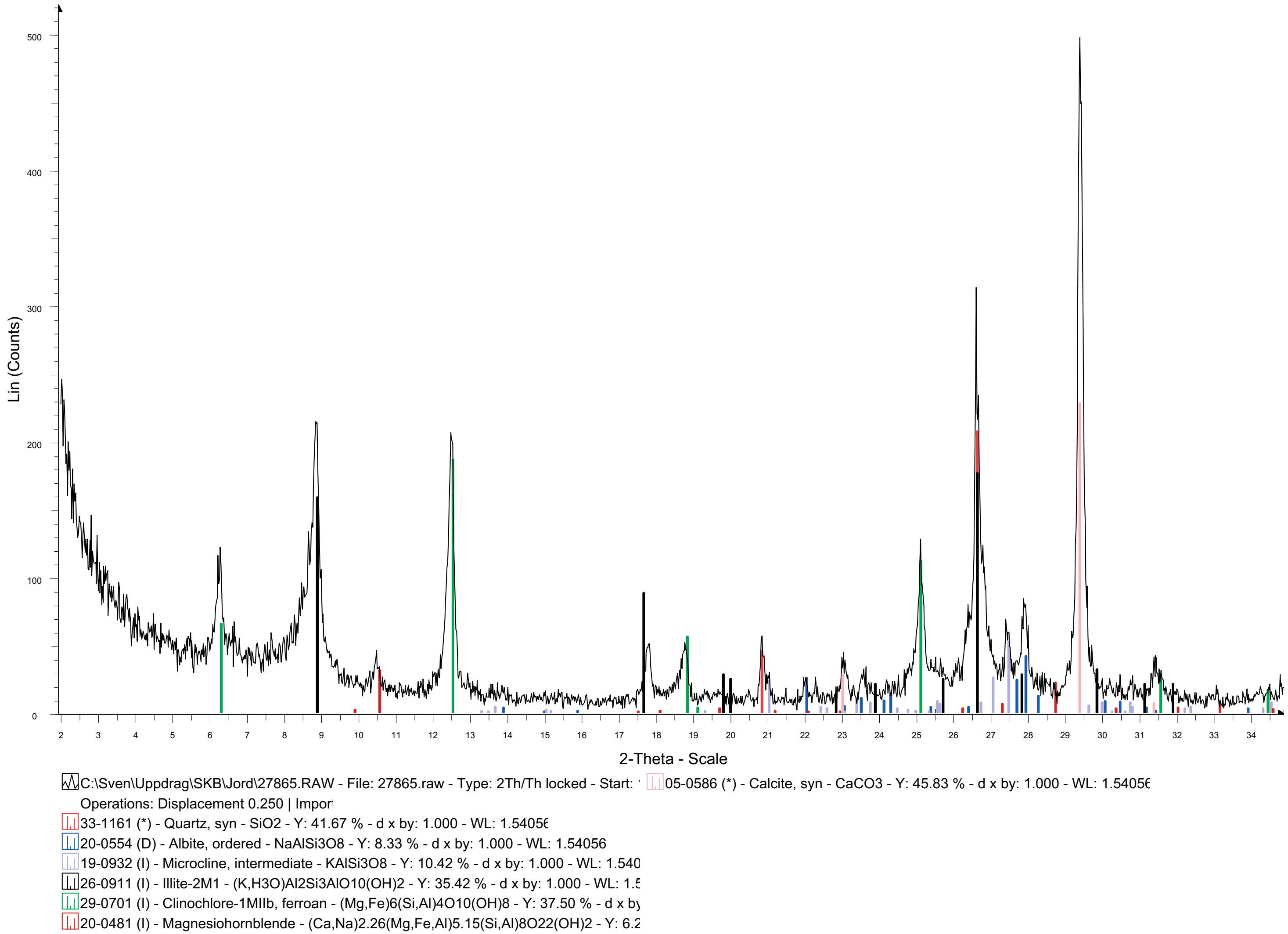

Figure A2-4. *X-ray diffractogram showing the distribution of clay minerals (SFM0004_1, 2.5–3.0).*

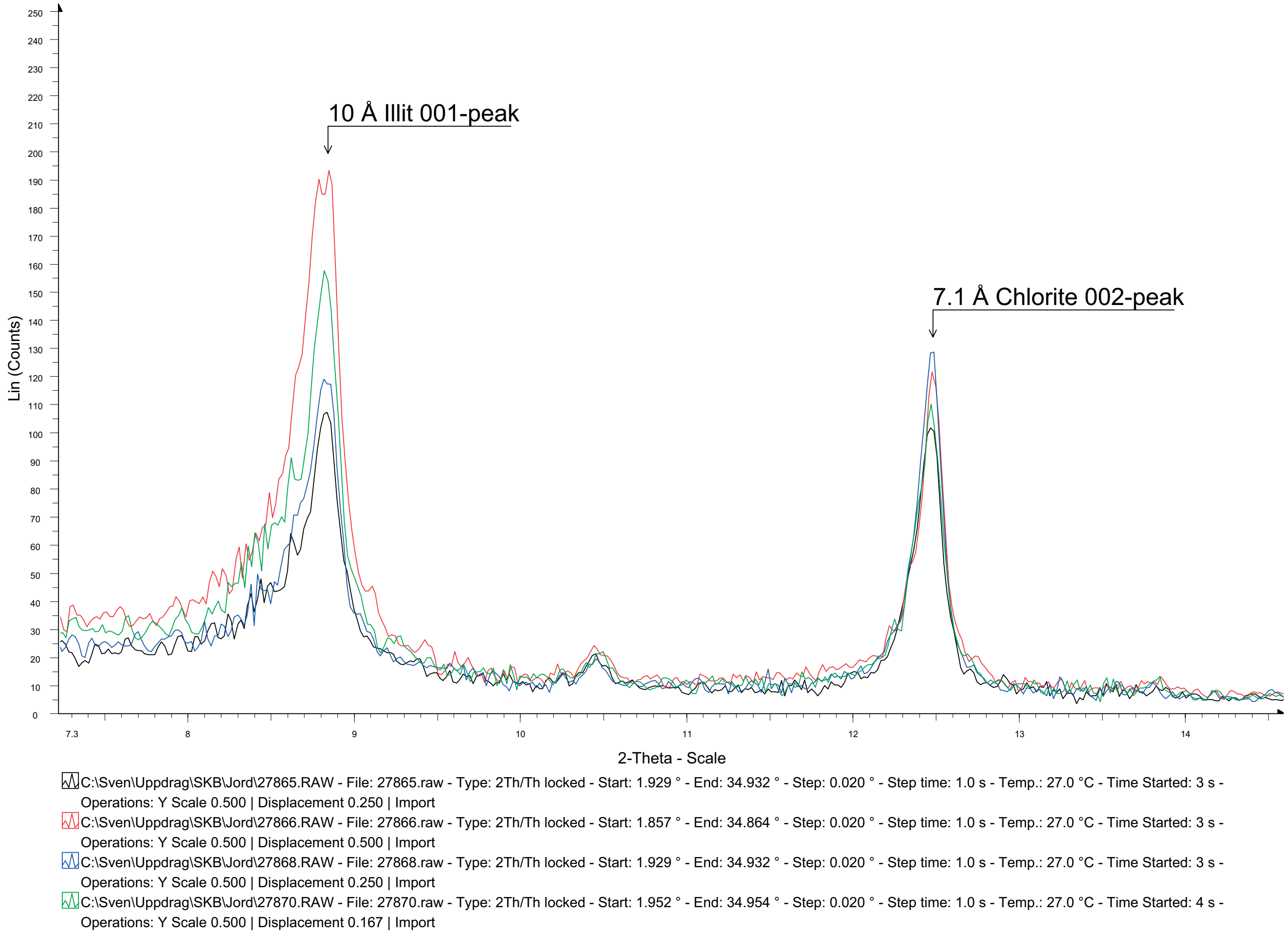

Figure A2-5. *The illite and chlorite peaks in the four samples analysed for clay minerals. Brown=SFM004_1, red=HFM07_1, blue=HFM05_2, green=HFM08_2. The illite/chlorite ratio is higher in the two clayey tills (HFM07_1 and HFM08_2).*