Technical Report

Title: ***XRD Mineralogical Analysis of DGR-1 and DGR-2 Core***

Document ID: **TR-08-01**

Authors: **Aniceta Skowron & Eric Hoffman**
Activation Laboratories Ltd.,
Ancaster, Ontario

Revision: **0**

Date: **April 16, 2009**

DGR Site Characterization Document
Intera Engineering Project 06-219

Intera Engineering DGR Site Characterization Document		
Title:	XRD Mineralogical Analysis of DGR-1 and DGR-2 Core	
Document ID:	TR-08-01	
Revision Number:	0	Date: April 16, 2009
Author(s):	Aniceta Skowron and Eric Hoffman, Actlabs, Ancaster, Ontario. Edited by Richard Jackson	
Technical Review:	Kenneth Raven; Branko Semec (NWMO)	
QA Review:	John Avis	
Approved by:	Kenneth Raven	

Document Revision History		
Revision	Effective Date	Description of Changes
0	April 16, 2009	Initial Release

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

1 Introduction

Intera Engineering Ltd. has been contracted by Ontario Power Generation (OPG) to implement the Geoscientific Site Characterization Plan (GSCP) for the Bruce site located on Lake Huron, Ontario. The purpose of this site characterization work is to assess the suitability of the Bruce site to construct a Deep Geologic Repository (DGR) to store low-level and intermediate-level radioactive waste. The GSCP is described by Intera Engineering Ltd. (2006).

As part of the GSCP, Intera Engineering Ltd. retained Activation Laboratories ("ActLabs") of Ancaster, Ontario to undertake mineralogical testing of cores collected from boreholes DGR-1 and DGR-2. This Technical Report summarizes the results of the x-ray diffraction (XRD) analysis of DGR-1 and DGR-2 core samples to quantify the major minerals present in the cores and to identify the clay minerals present in the clay-sized fraction.

Work described in this Technical Report was undertaken in accordance with Test Plan TP-07-01 – Laboratory Testing of DGR-1 and DGR-2 Solid Core for Geochemistry & Mineralogy (Intera Engineering Ltd., 2007a), which was prepared following the general requirements of the DGR Project Quality Plan (Intera Engineering Ltd., 2007b).

2 Background

Core samples of 76 mm diameter were collected during diamond coring of boreholes DGR-1 and DGR-2 at the Bruce site from January until August, 2007. All core samples were vacuum sealed within nitrogen flushed polyethylene and aluminium foil/polyethylene bags following core retrieval and the general preservation and handling requirements of TP-06-10 (Intera Engineering Ltd., 2007c). Thirty-four preserved core samples from boreholes DGR-1 and DGR-2 were shipped to ActLabs under chain of custody procedures (following procedure DGR P4). Table 1 lists the Intera sample identifier based on depth in metres below ground surface (mBGS), geologic formation and description of the 14 DGR-1 samples selected for mineralogical testing.

Table 1 Formations, Description & Depths of DGR-1 Core Samples

Intera Sample ID	*Formation*	*Sample Description*
DGR1-049.16	Amherstburg	Light brown-grey, fine grained dolostone
DGR1-097.08	Bois Blanc	Grey-brown cherty dolostone
DGR1-130.03	Bass Islands	Dark grey, very fine grained dolostone
DGR1-156.63	Bass Islands	Grey-brown fine grained dolostone
DGR1-231.49	Salina E Unit	Grey-tan brecciated dolostone
DGR1-267.78	Salina B Unit	Tan argillaceous dolostone
DGR1-322.19	Salina A2 Unit	Massive light grey-blue anhydritic dolostone
DGR1-361.76	Salina A1 Unit	Grey argillaceous dolostone
DGR1-399.85	Gasport	Grey dolomitic limestone
DGR1-419.99	Cabot Head	Red-maroon massive shale
DGR1-446.25	Manitoulin	Tan-grey, fine-grained, crystalline dolostone
DGR1-455.45	Queenston	Red-maroon massive shale
DGR1-456.01	Queenston	Red-maroon massive shale
DGR1-460.77	Queenston	Grey-green and red-maroon shale

Table 2 lists similar information for the 19 DGR-2 samples. One sample – DGR2-687.42 – was sent for petrographic analysis but was not analysed by XRD or lithogeochemistry and SEM/EDS.

Table 2 Formations, Descriptions & Depths of DGR-2 Core Samples

Intera Sample ID	*Formation*	*Sample Description*
DGR2-451.33	Queenston	Red-maroon massive shale
DGR2-482.45	Queenston	Interbedded green shale and grey limestone
DGR2-508.93	Queenston	Red-maroon shale
DGR2-535.56	Georgian Bay	Interbedded grey-green shale and limestone
DGR2-550.28	Georgian Bay	Interbedded dark grey-green shale and limestone
DGR2-570.73	Georgian Bay	Interbedded dark grey-green shale and limestone
DGR2-590.10	Georgian Bay	Dark grey-green shale
DGR2-606.62	Georgian Bay	Dark grey-green shale
DGR2-606.96	Georgian Bay	Dark grey-green shale
DGR2-626.29	Blue Mountain	Dark grey-green massive shale
DGR2-644.49	Blue Mountain	Dark grey-black massive shale
DGR2-659.31	Collingwood Member, Cobourg	Interbedded grey shale and argillaceous limestone
DGR2-669.27	Cobourg	Grey argillaceous limestone
DGR2-677.93	Cobourg	Mottled grey argillaceous limestone
DGR2-695.51	Sherman Fall	Grey argillaceous limestone
DGR2-704.87	Sherman Fall	Grey fossiliferous argillaceous limestone
DGR2-745.97	Kirkfield	Interbedded grey shale and argillaceous limestone
DGR2-816.85	Gull River	Grey argillaceous limestone/mudstone
DGR2-844.95	Cambrian	Tan-grey argillaceous dolostone with minor sandstone

The core samples were inspected by Actlabs and Dr. Eva Schandl on receipt at Actlabs. If the cores were laminated with shale intervals in the case of carbonate rocks or were principally shale, then the shale was retained by Actlabs and analysed for clay-mineral identification of oriented (basal-plane) samples based upon standard ethylene glycol treatment and sample heating to 400 °C and 550 °C. In this case, the thin sections were prepared from the bulk rock and results recorded by photomicrographs (i.e., TR-07-12, Intera Engineering Ltd., 2009a). That results in Dr. Schandl's report being intentionally biased towards the carbonate rocks rather than the shales. In addition, Actlabs analyzed the whole rock by XRD to determine mineral concentrations.

ActLabs determined the mineralogy of both the DGR-1 and DGR-2 cores by x-ray diffraction – this report – and by petrography through Dr. Schandl, whose results are recorded in TR-07-12 (Intera Engineering Ltd., 2009a). Additionally, DGR-1 and DGR-2 cores underwent a complete 'lithogeochemical' analysis that included measurement of 10 oxides and approximately 50 trace elements. These data and the results of analysing the Ordovician shales and argillaceous limestones by scanning electron microscopy (SEM) coupled with an energy dispersive spectrometer (EDS) are presented in TR-08-02 (Intera Engineering Ltd, 2009b).

Sample descriptions provided in Tables 1 and 2, are based on the general core log descriptions of the individual core runs that provided the cores selected for laboratory testing. For this reason and because the observed variability of lithology within individual core samples, the descriptions provided in Tables 1 and 2 may show slight variations from those that may be determined from mineralogical results given in Section 3.

3 Methods

3.1 Whole Rock

The samples were pulverized, ground in a ceramic mortar and back-loaded in an aluminum sample holder to minimize preferred orientation of the crystallites. Powder XRD was used to identify and quantify minerals present in the samples. The measurements were performed using a Panalytical X'Pert Pro PW3040 Multi Purpose Diffraction system controlled and operated by Panalytical B.V. X'Pert Data Collector software, Version 2.2a. Experimental data were processed using Panalytical B.V. X'Pert HighScore software, Version 2.2.1. The measurement conditions were:

Start Position [°2Theta]	3.0100
End Position [°2Theta]	89.9900
Step Size [°2Theta]	0.0200
Scan Step Time [s]	1.0000
Scan Type	Continuous
Divergence Slit Type	Fixed
Divergence Slit Size [°]	1.0000
Receiving Slit Size [mm]	0.4000
Measurement Temperature [°C]	25.00
Anode Material	Cu
K-Alpha1 [Å]	1.54060
K-Alpha2 [Å]	1.54443
Generator Settings	50 mA, 40 kV
Spinning	2rps

3.2 Clay Fraction

A four-step process was followed before X-ray diffraction was performed using Phillips PW 1050 diffractometer equipped with Cu X-ray source and operated at 40 kV and 30 mA.

Firstly, the clay fractions were separated from the samples by milling the cores and soaking the resulting powders in purified water for several hours, sonicating and decanting the clay fraction after timed sedimentation. In order to isolate more clay from some DGR-2 carbonate rock samples with low clay content (i.e., DGR2-677.93, DGR2-695.51, DGR2-816.85, & DGR2-844.95), these samples were repeatedly soaked in purified water, sonicated and centrifuged ten times.

Secondly, the decanted suspensions containing the clay fraction were filtered through a 0.4 μm filter. In most cases only a small amount of fine fraction was obtained. For such cases the material collected on the filter was re-dispersed in a very small amount of purified water and the concentrated suspension was placed on a glass slide and allowed to dry at room temperature. If a substantial amount of clay fraction material was obtained, several drops of the suspension were dried on the glass slide to obtain the oriented film. The film was dried and used for X-ray diffraction.

Subsequently, the samples were placed in a desiccator with ethylene glycol, evacuated for 15 minutes and left to saturate overnight. The samples were examined by X-ray diffraction immediately after taking them out of the desiccator. Finally, the glycolated samples were heated at 400 °C and at 550 °C for 1½ hours and examined by X-ray diffraction after each treatment.

4 Results

4.1 Whole Rock

Mineral identification was performed using search and match feature of X'Pert HighScore software. Appendix A shows the results of search and match analysis for selected samples (DGR1-322.19, DGR1-399.85, DGR2-606.62, DGR2-816.85 and DGR2-844.95). The samples were chosen such that every mineral identified in the submitted samples is represented and its characteristic diffraction lines are shown for reference. Accordingly, the appended diffractograms show the lines from all identified minerals first and additionally, the diffraction lines from every mineral encountered in selected samples is shown separately for reference.

Once the minerals were identified, their structures, as referenced in structural crystallographic databases, were used for full profile Rietveld refinement[1] to obtain the relative concentrations of the minerals. The calculated profiles were fitted to the experimental profiles by the full profile Rietveld refinement with the following structural parameters allowed to vary: scale factor, unit cell parameters (only for the initial steps), preferred orientation, zero shift and the peak shape. Appendix B presents results of the Rietveld analysis for all DGR1 and DGR2 core samples. The red curve shows the measured diffraction pattern, and the blue curve shows the calculated pattern. The lower graph shows the difference between the measured and the calculated patterns. Tables 3 and 4 present the results of the quantitation by the Rietveld approach for DGR-1 and DGR-2, respectively.

Calcite, dolomite and quartz are common minerals throughout the DGR-1 cores, i.e., throughout the Devonian and Silurian sedimentary sequence of rocks. With depth, the clay minerals illite and chlorite [clinochlore] become more common as shale units are encountered. Soluble minerals such as gypsum, anhydrite and halite become more common beneath the Salina F Unit, with halite present in the Cabot Head and Manitoulin Formations.

The Upper Ordovician shales tend to be dominated by illite and quartz, while the middle Ordovician carbonates are principally calcite with minor dolomite and illite. However, the deepest samples – from the Gull River (DGR2-816.85) and the Cambrian (DGR2-844.95) formations were principally dolomite. Pyrite was present in the shales typically at a few percent. Soluble minerals were relatively rare with halite detected within the Queenston (447-518 mBGS) and Georgian Bay (DGR2-606.62) Formations and anhydrite in the Sherman Fall Formation (DGR2-704.87). The samples DGR2-669.27 and DGR2-677.93 were checked for presence of crystalline forms of anhydrous and hydrated magnesium sulphate, $MgSO_4$. The experimental patterns were compared with the simulated patterns of anhydrous and hydrated magnesium sulphate from the PDF4/Minerals database. No evidence of these crystal forms were found in DGR2-669.27 and DGR2-677.93.

[1] The Reitveld method is "a *standardless* full profile approach to quantitative phase analysis", i.e., of mineral phases in an X-ray powder-diffraction pattern involving a least-squares fit to the diffractogram. See Raudsepp, M. and E. Pani, 2003, chapter 8: *Application of Rietveld Analysis to Environmental Mineralogy*, in Environmental Aspects of Mine Wastes, editors, J.L. Jambor, D.W. Blowes and A.I.M. Ritchie, Mineralogical Association of Canada, Short Course Series Volume 31, pp. 165-180.

Table 3 Summary of Mineral Identification and Quantification for DGR-1 Cores

Intera sample ID	*Minerals Present*	*Concentration (%)*	*Notes*
DGR1-049.16	Calcite Dolomite Quartz	41.8 55.7 2.5	
DGR1-097.08	Calcite Dolomite Quartz Illite	43.3 21.7 34.9 0.1	The quartz content is chert
DGR1-130.03	Dolomite Quartz	99.7 0.3	
DGR1-156.63	Dolomite Quartz	98.8 1.2	
DGR1-231.49	Dolomite Quartz Gypsum Pyrite Illite Clinochlore	76.1 5.1 13.5 0.1 4.3 0.9	Small unidentified peak at 27.5^{o} 2θ.
DGR1-267.78	Dolomite Quartz Gypsum Halite Illite Clinochlore	29.6 22.7 15.0 0.7 28.7 3.2	
DGR1-322.19	Anhydrite Gypsum Calcite Dolomite Quartz Feldspar (Sr)	84.6 2.2 7.8 3.4 1.6 0.3	Small unidentified peak at 32.8^{o} 2θ
DGR1-361.76	Calcite Dolomite Quartz Anhydrite Illite	81.1 7.7 1.8 1.5 7.9	Small unidentified peaks at 27.5^{o} and 28.4^{o} 2θ
DGR1-399.85	Calcite Dolomite Quartz Wuestite Illite	75.9 18.7 1.6 0.3 3.1	Aluminum diffraction peaks due to sample holder material.
DGR1-419.99	Dolomite Quartz Halite Illite Clinochlore	58.8 17.3 1.1 17.9 4.8	Not full fit of some peaks due to strong preferred orientation of the clay minerals.
DGR1-446.25	Dolomite Quartz Halite Hematite Illite Clinochlore	13.4 31.6 0.4 3.1 47.2 4.3	
DGR1-455.45	Calcite Dolomite Quartz	35.3 8.6 15.2	

	Hematite Clinochlore Illite	1.1 9.7 30.1	
DGR1-456.01	Calcite Dolomite Quartz Hematite Halite Clinochlore Illite	33.1 22.2 16.0 1.4 3.1 7.3 16.8	
DGR1-460.77	Calcite Dolomite Quartz Gypsum Clinochlore Illite	41.1 10.8 11.9 0.5 8.4 27.3	Not full fit of some peaks due to strong preferred orientation of the clay minerals

Table 4 Summary of Mineral Identification and Quantification for DGR-2 Cores

Intera Sample ID	*Minerals Present*	*Concentration (%)*	*Notes*
DGR2-451.33	Calcite Dolomite Quartz Clinochlore Illite	34.7 31.4 11.1 5.2 17.5	
DGR2-482.45	Calcite Dolomite Quartz Clinochlore Illite	17.1 17.5 21.3 8.7 35.5	Small unidentified peak at 27.5° 2θ
DGR2-508.93	Calcite Dolomite Quartz Clinochlore Illite	24.2 16.1 20.2 7.2 32.3	Small unidentified peak at 27.5° 2θ
DGR2-535.56	Calcite Dolomite Quartz Clinochlore Illite	11.2 9.5 20.0 8.4 51.0	Small unidentified peaks at 19.1° and 27.5° 2θ
DGR2-550.28	Calcite Dolomite Quartz Clinochlore Illite	6.4 12.1 30.2 14.0 37.3	Small unidentified peaks at 19.1° and 27.5° 2θ
DGR2-570.73	Calcite Dolomite Quartz Clinochlore Illite	3.2 8.9 28.5 11.2 48.2	Small unidentified peaks at 18.8° and 24.5° 2θ
DGR2-590.10	Calcite Dolomite Quartz Pyrite	5.2 1.7 46.3 2.9	

	Clinochlore Illite	10.1 33.7	
DGR2-606.62	Calcite Dolomite Quartz Halite Clinochlore Illite	15.9 18.0 33.5 1.4 8.0 23.3	
DGR2-606.96	Calcite Dolomite Quartz Pyrite Clinochlore Illite	3.5 7.9 43.1 1.8 12.2 31.6	Small unidentified peak at 65.2^o 2θ
DGR2-626.29	Calcite Dolomite Quartz Pyrite Clinochlore Illite	4.1 7.8 45.2 1.4 9.9 31.6	Small unidentified peak at 65.2^o 2θ
DGR2-644.49	Calcite Dolomite Quartz Pyrite Clinochlore Illite	11.5 2.2 47.2 2.8 8.5 27.8	
DGR2-659.31	Calcite Dolomite Quartz Illite	74.2 21.3 3.8 0.8	
DGR2-669.27	Calcite Dolomite Quartz Illite	80.5 8.1 6.2 5.2	
DGR2-677.93	Calcite Dolomite Quartz Illite	89.5 6.9 0.1 3.1	A small amount of gypsum was possibly present in the clay fraction specimen, which was not detected in the bulk sample. It is not possible to conclude if the original sample contained gypsum or anhydrite, since the separation of clay fraction involved soaking the sample in water.
DGR2-695.51	Calcite Dolomite Quartz Feldspar (Sr) Illite	56.7 42.4 0.8 0.1 0.0	Small unidentified peak at 27.5^o 2θ
DGR2-704.87	Calcite Dolomite Quartz Anhydrite Illite	82.9 4.2 5.9 1.8 5.2	
DGR2-745.97	Calcite Dolomite Quartz Feldspar (Sr) Illite	88.6 3.1 5.0 0.3 3.0	Small unidentified peak at 32.3^o 2θ

DGR2-816.85	Calcite Dolomite Quartz	19.9 78.8 1.2	Small unidentified peak at 27.5° 2θ
DGR2-844.95	Dolomite Quartz Microcline	97.0 2.9 0.1	Small unidentified peak at 29.5° 2θ

4.2 Clay Fraction

Typical XRD patterns of the four diagnostic preparations used for clay identification are shown in Figure 1. The low angle diffraction peaks can be assigned to chlorite and illite as indicated by the arrows. The changes (or their absence) in the positions or/and intensities of the peaks for the four preparations are used for the clay identification as shown in the summary Table 5 for illite and chlorite (basal peak orders in square parentheses).

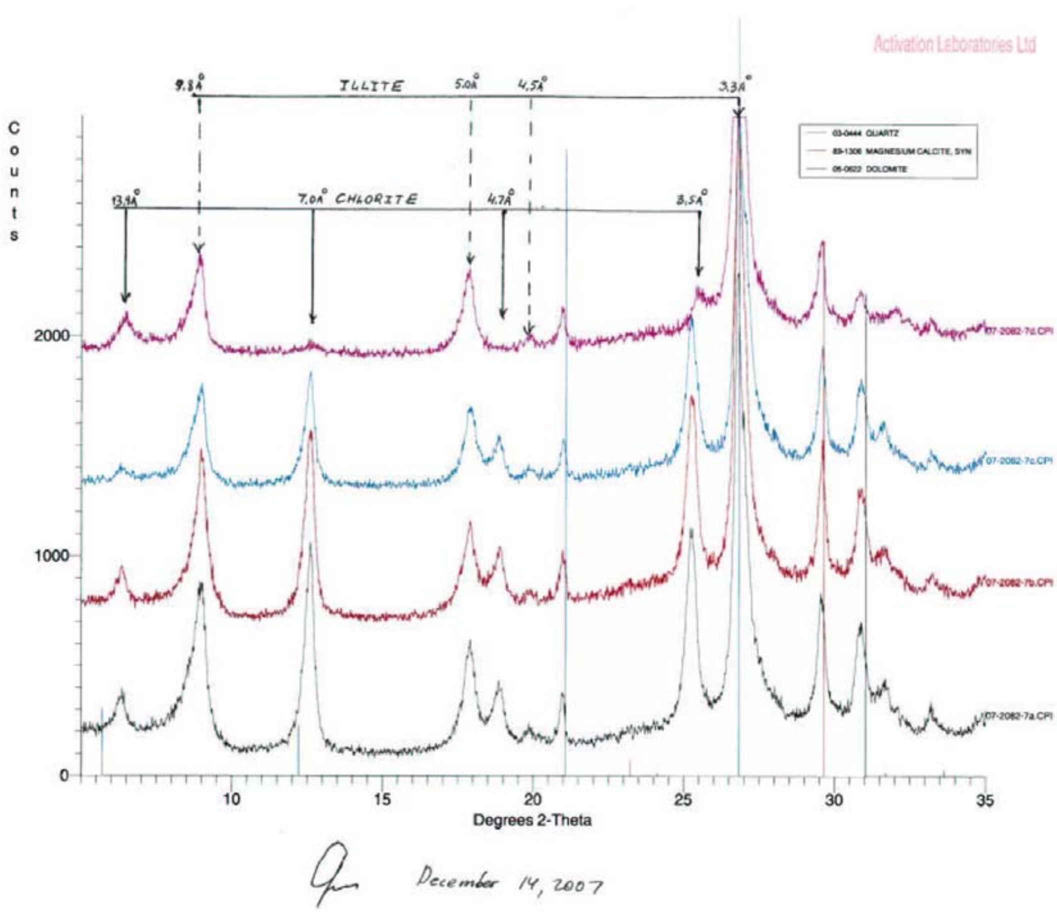


Figure 1 Typical X-Ray Diffraction Patterns of the Four Diagnostics Preparations Used for Clay Identification. Illite and Chlorite Peaks are Indicated by the Arrows

No substantial amount of clay fraction could be separated from six of the fourteen samples of DGR-1 core. The remaining eight samples contained clay fraction in varying amounts and in all of these samples Illite or Illite and Chlorite were identified. Table 6 summarizes the clay identification in the DGR-1 core; where clay was identified, it was typically illite and chlorite. Most of the samples of DGR-2 core also contained illite and chlorite, as shown in Table 7. The clay mineral diffractograms are shown in Appendix C.

Table 5 Typical Diffraction Peaks Positions and Their Induced Changes Used in the Identification of Clay Minerals Present in DGR-1 and DGR-2 Cores

Treatment	***Peak position***	***Peak position***	***Peak position***
Air dried oriented	~7 Å	~10 Å	~14 Å
Ethylene glycol	No change	No change	No change
Heated ≈ 400º C	No change	No change	No change
Heated ≈ 550º C	Destroyed	No change	No change
Identification →	**Chlorite [002]**	**Illite [001]**	**Chlorite [001]**

Table 6 Identification of Clay and Other Minerals in the Fine Fraction of DGR-1 Cores

Intera Sample ID	***Clay Minerals Present***	***Other Minerals Present in the Fine Fraction***
DGR1-049.16	No clay	Calcite, Dolomite, possibly Hillebrandite
DGR1-097.08	No clay	Quartz, Magnesium Calcite
DGR1-130.03	No clay	Dolomite
DGR1-156.63	No clay	Dolomite, Quartz
DGR1-231.49	Illite, Chlorite	Dolomite, Quartz, Gypsum
DGR1-267.78	Illite, Chlorite	Dolomite, Quartz, Gypsum
DGR1-322.19	No clay	Dolomite, Quartz, Gypsum
DGR1-361.76	Illite	Dolomite, Quartz, Gypsum, possibly Hillebrandite
DGR1-399.85	No clay	Magnesium Calcite, Halite
DGR1-419.99	Illite, Chlorite	Quartz, Dolomite
DGR1-446.25	Illite, Chlorite	Quartz, Dolomite
DGR1-455.45	Illite, Chlorite	Quartz, Calcite, Dolomite
DGR1-456.01	Illite, Chlorite	Quartz, Calcite, Dolomite
DGR1-460.77	Illite, Chlorite	Quartz, Calcite, Dolomite

Table 7 Identification of Clay and Other Minerals in the Fine Fraction of DGR-2 Cores

Intera Sample ID	*Clay Minerals Present*	*Other Minerals Present in the Fine Fraction*
DGR2-451.33	Illite, Chlorite	Quartz, Calcite
DGR2-482.45	Illite, Chlorite	Quartz, Calcite, Dolomite
DGR2-508.93	Illite, Chlorite	Quartz, Calcite, Dolomite
DGR2-535.56	Illite, Chlorite	Quartz, Calcite, Dolomite
DGR2-550.28	Illite, Chlorite	Quartz, Calcite, Dolomite
DGR2-570.73	Illite, Chlorite	Quartz, Calcite, Dolomite
DGR2-590.10	Illite, Chlorite	Quartz, Calcite, Dolomite
DGR2-606.62	Illite, Chlorite	Quartz, Calcite, Dolomite
DGR2-606.96	Illite, Chlorite	Quartz, Calcite, Dolomite
DGR2-626.29	Illite, Chlorite	Quartz, Calcite,
DGR2-644.49	Illite, Chlorite	Quartz, Calcite,
DGR2-659.31	Illite, Chlorite	Magnesium Calcite, Quartz
DGR2-669.27	Illite, Chlorite	Magnesium Calcite, Quartz
DGR2-677.93	No clay	Magnesium Calcite, Quartz + Gypsum or Anhydrite
DGR2-695.51	Illite	Magnesium Calcite
DGR2-704.87	Illite, Chlorite	Quartz, Magnesium Calcite
DGR2-745.97	Illite, Chlorite	Magnesium Calcite, Quartz
DGR2-816.85	No clay	Magnesium Calcite, Quartz, Dolomite
DGR2-844.95	No clay	Dolomite, Quartz, Magnesium Calcite

5 Data Quality and Use

As indicated in Tables 3 and 4, for some samples residual low intensity diffraction peaks could not be identified and hence a corresponding mineral(s) was not included in the Rietveld refinement. This introduces an error into the quantification since the calculation procedure constrains the total concentration to 100%. An unidentified peak at 27.5 deg 2θ was present in several diffraction patterns, but peaks at other angles were also present although less frequently. The performed Rietveld refinement did not incorporate possible ion substitutions in the crystal structures as variables for the refinement. Taking such substitutions into account might improve the refinement fit at the expense of the number of variables to consider and to justify.

The preparation of clay-sized fraction samples would have resulted in the dissolution of any soluble minerals such as halite, anhydrite and gypsum. Therefore, the absence of soluble minerals in these XRD patterns is to be expected. By the same mechanism, the possible detection of gypsum in the Cobourg Formation sample (Table 7, DGR2-677.93) may have been caused by the hydration of anhydrite to gypsum during sample preparation.

6 Conclusions

Cores from DGR-1 and DGR-2 were examined by X-ray powder diffraction both in whole-rock and clay-sized fractions. Calcite, dolomite and quartz were the most common minerals in the Silurian and Devonian formations. Gypsum and anhydrite were common in some of the deeper Salina units and halite was detected in the Salina B Unit and the Gasport Formation of the Middle Silurian and in the Cabot Head and Manitoulin Formations of the Lower Silurian. Clay minerals were sometimes absent in samples collected above the Cabot Head Formation (411-431 mBGS), however when present, illite was the principal clay mineral observed in DGR-1 cores.

The Upper Ordovician shales (447-652 mBGS) sampled by DGR-2 were relatively uniform in mineralogical properties. Calcite, dolomite and quartz comprised 40-80% of the total minerals with illite, chlorite (clinochlore) and pyrite making up the balance. Halite was identified in several Queenston samples and one Georgian Bay sample. The Middle Ordovician limestones (652-778 mBGS) contained minor amounts of dolomite, quartz, chlorite and illite. The deepest sedimentary rocks examined by XRD – the Gull River Formation and the Cambrian – were both principally dolomite and lacked a clay fraction.

7 References

Intera Engineering Ltd., 2009a. Technical Report: Petrographic Analysis of DGR-1 and DGR-2 Cores, TR-07-12, Revision 0, April 16, Ottawa.

Intera Engineering Ltd., 2009b. Technical Report: Lithogeochemistry, SEM & EDS Analysis of DGR-1 and DGR-2 Cores. TR-08-02, Revision 0, April 16, Ottawa.

Intera Engineering Ltd., 2007a. Test Plan for Laboratory Testing of DGR-1 and DGR-2 Solid Core for Geochemistry and Mineralogy, TP-07-01, Revision 1, March 25, Ottawa.

Intera Engineering Ltd., 2007b. Project Quality Plan, DGR Site Characterization, Revision 3, January 17, Ottawa.

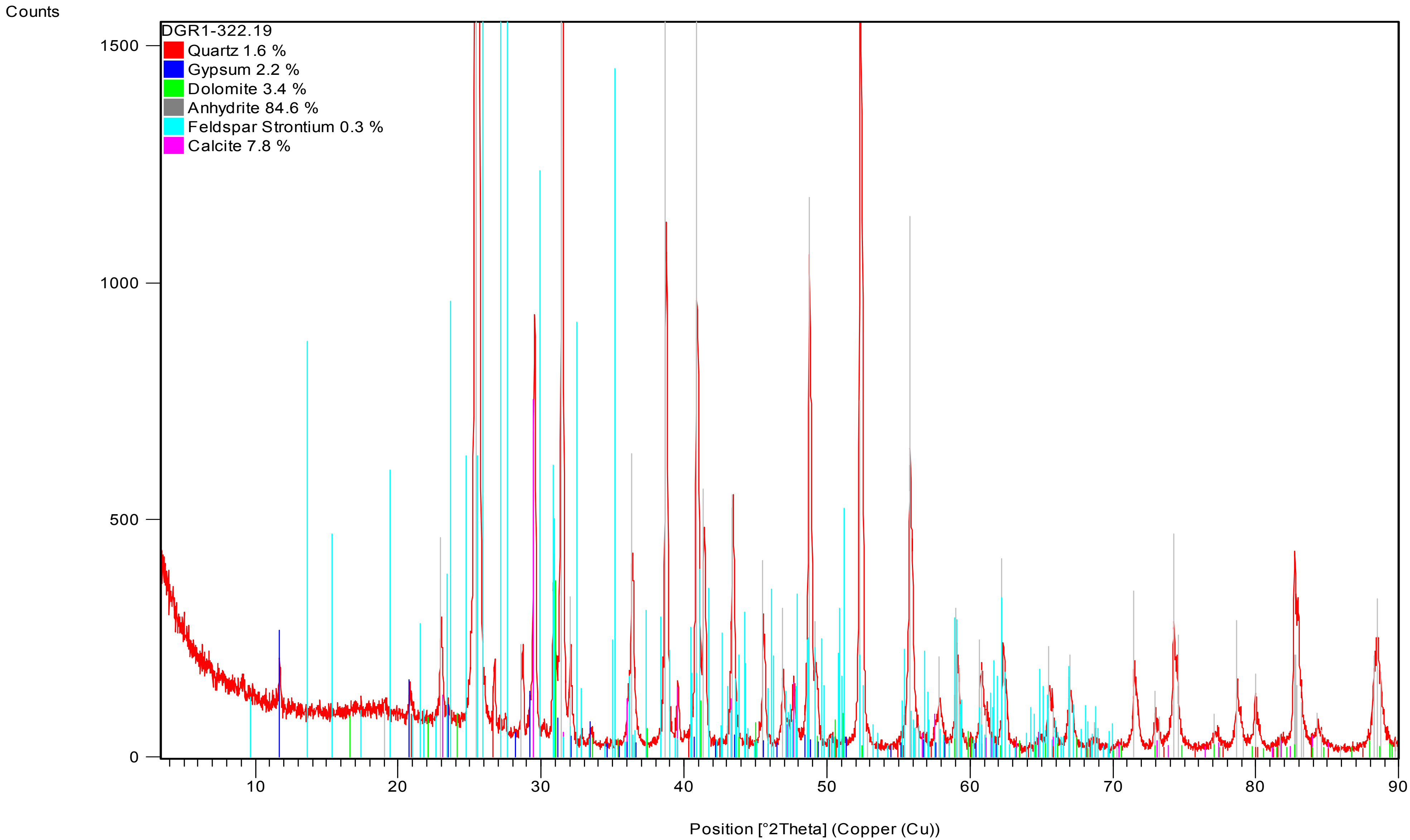
Intera Engineering Ltd., 2007c. Test Plan for DGR-1 & DGR-2 Core Sampling and Distribution, TP-06-10, Revision 4, May 14, Ottawa.

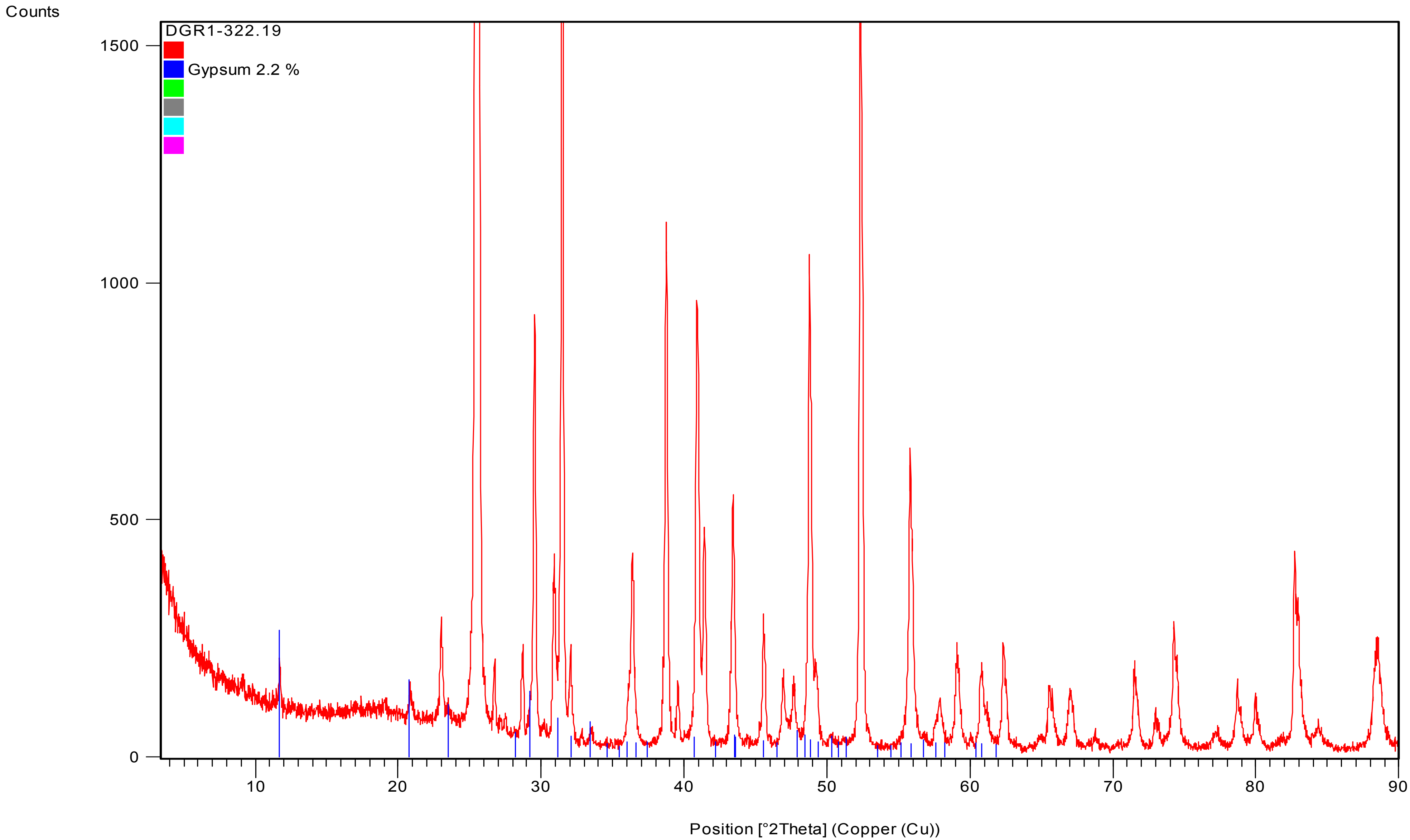
Intera Engineering Ltd., 2006. Geoscientific Site Characterization Plan, OPG's Deep Geologic Repository for Low and Intermediate Level Waste, Report INTERA 05-220-1, OPG 00216-REP-03902-00002-R00, April, Ottawa.

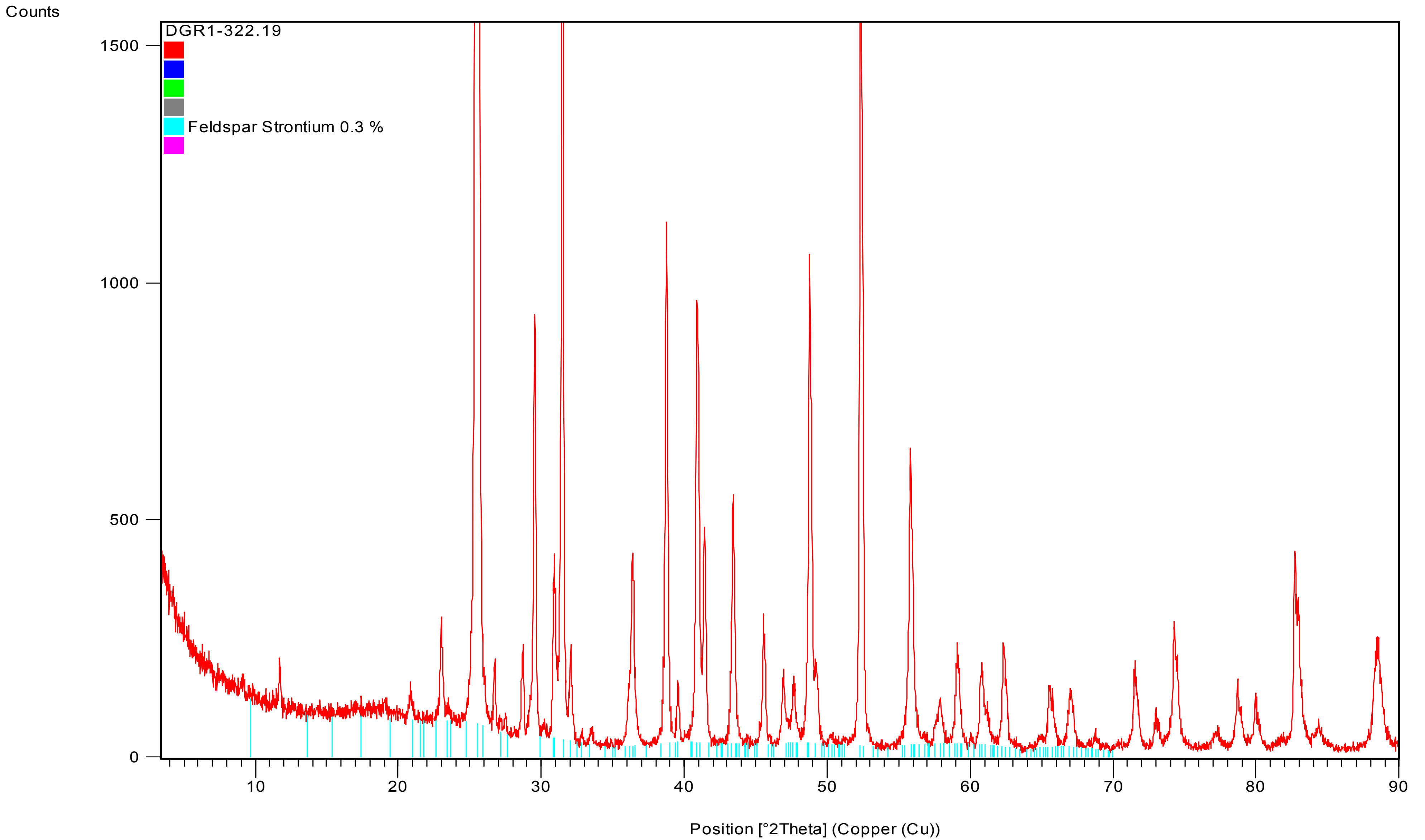
APPENDIX A

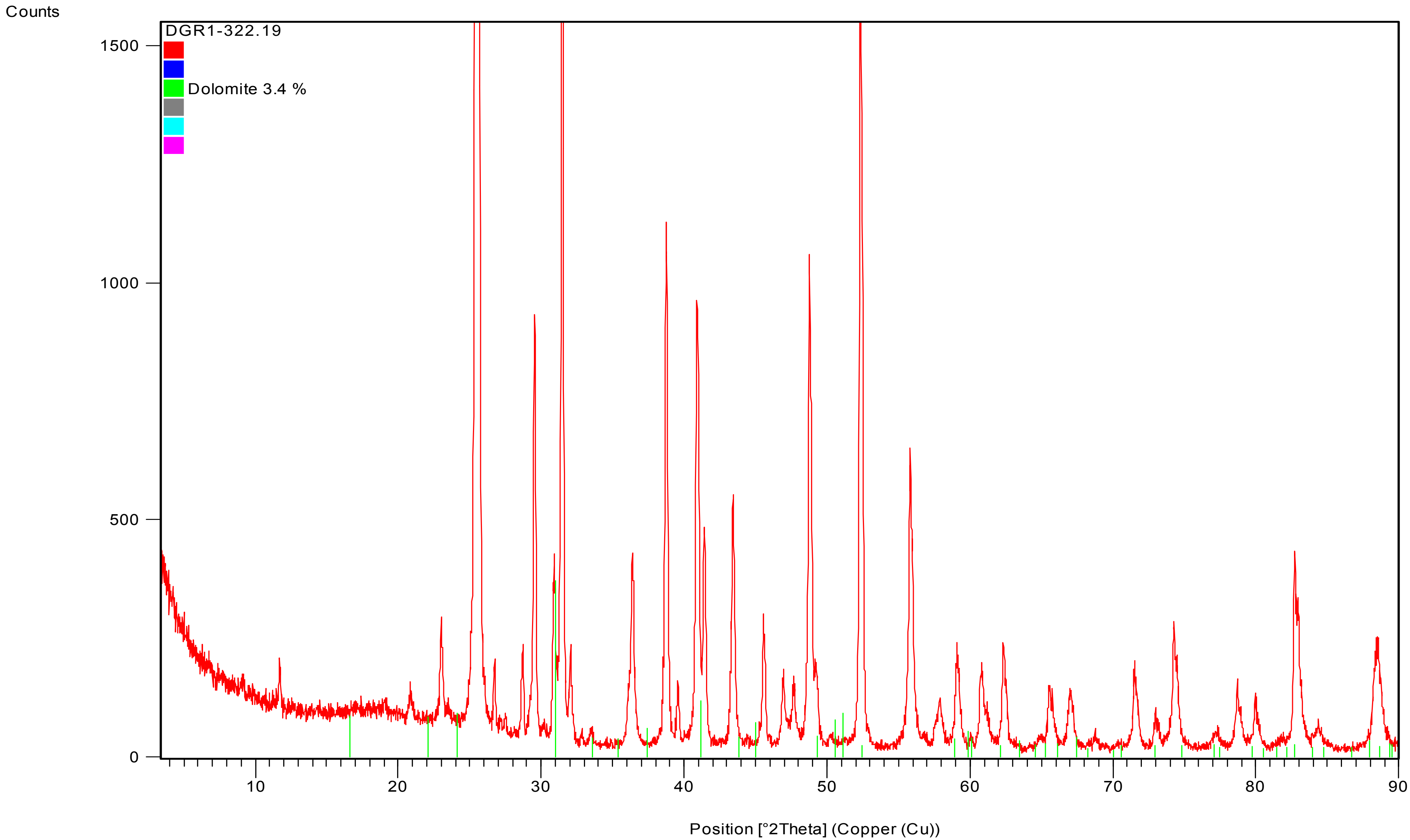
Search and Match Analysis for Selected Core Samples

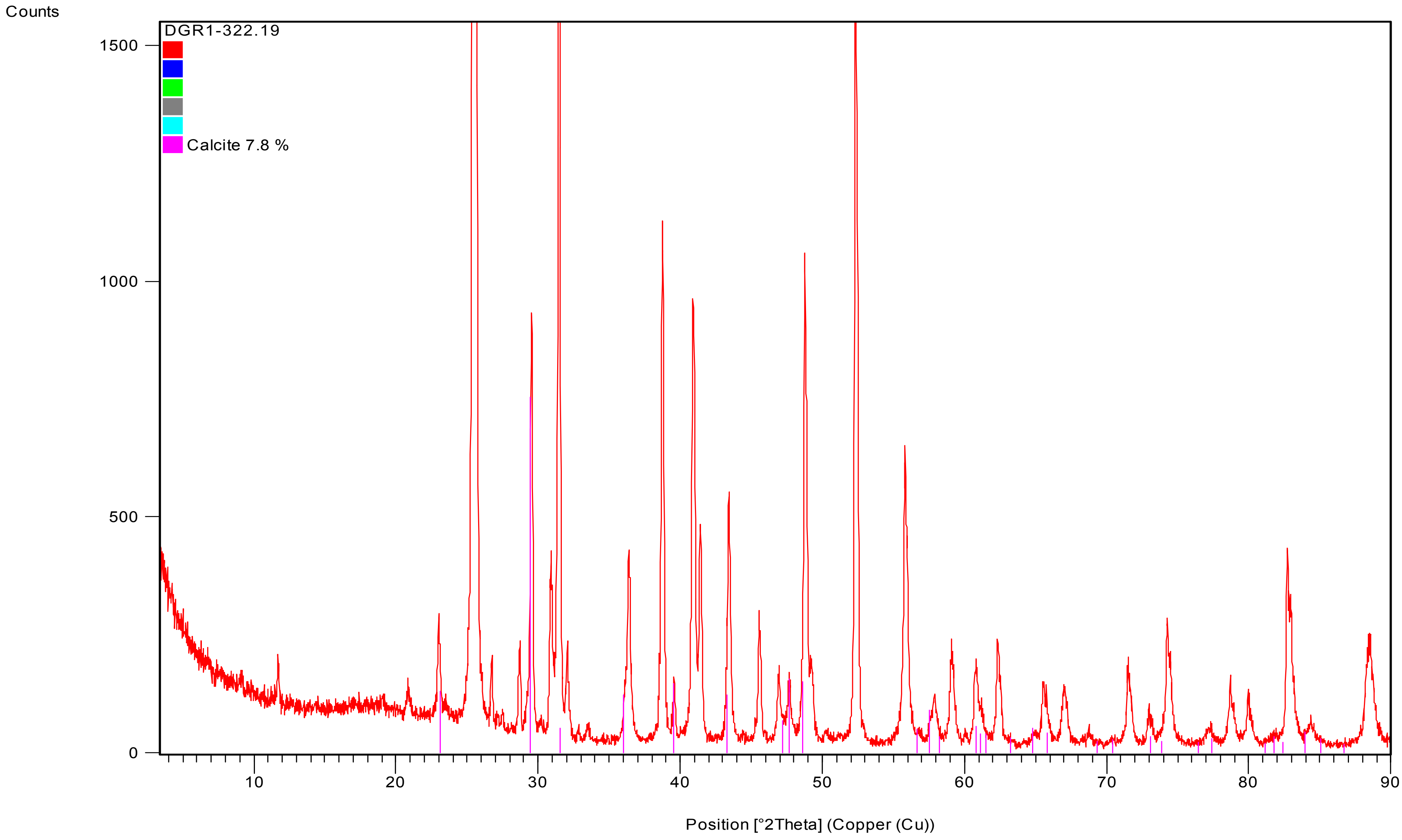
(DGR1-322.19, DGR1-399.85, DGR2-606.62, DGR2-816.85 and DGR2-844.95)

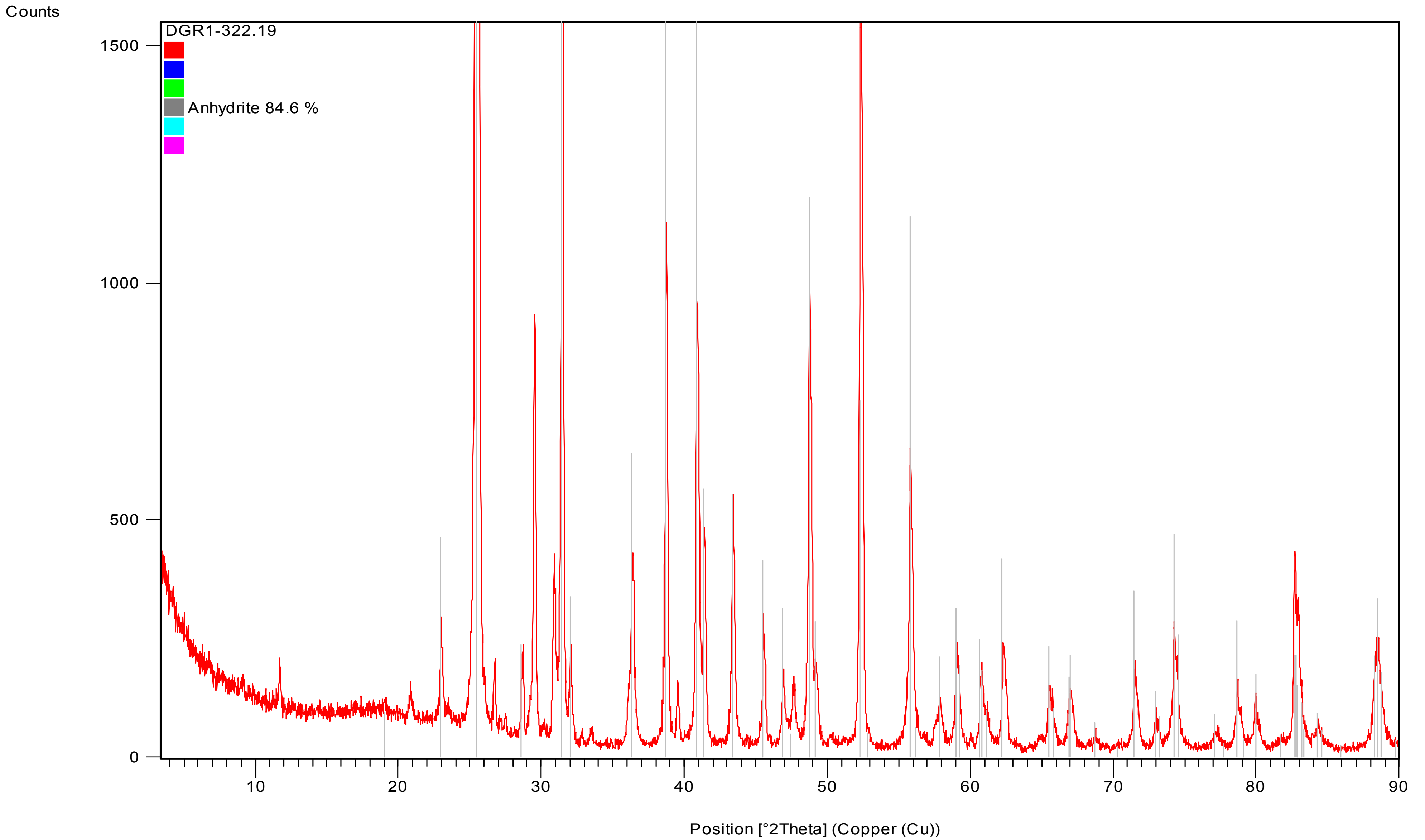

Counts
DGR1-322.19
Quartz 1.6 %
Gypsum 2.2 %
Dolomite 3.4 %
Anhydrite 84.6 %
Feldspar Strontium 0.3 %
Calcite 7.8 %
1500
1000
500
0
10
20
30
40
50
60
70
80
90
Position [°2Theta] (Copper (Cu))

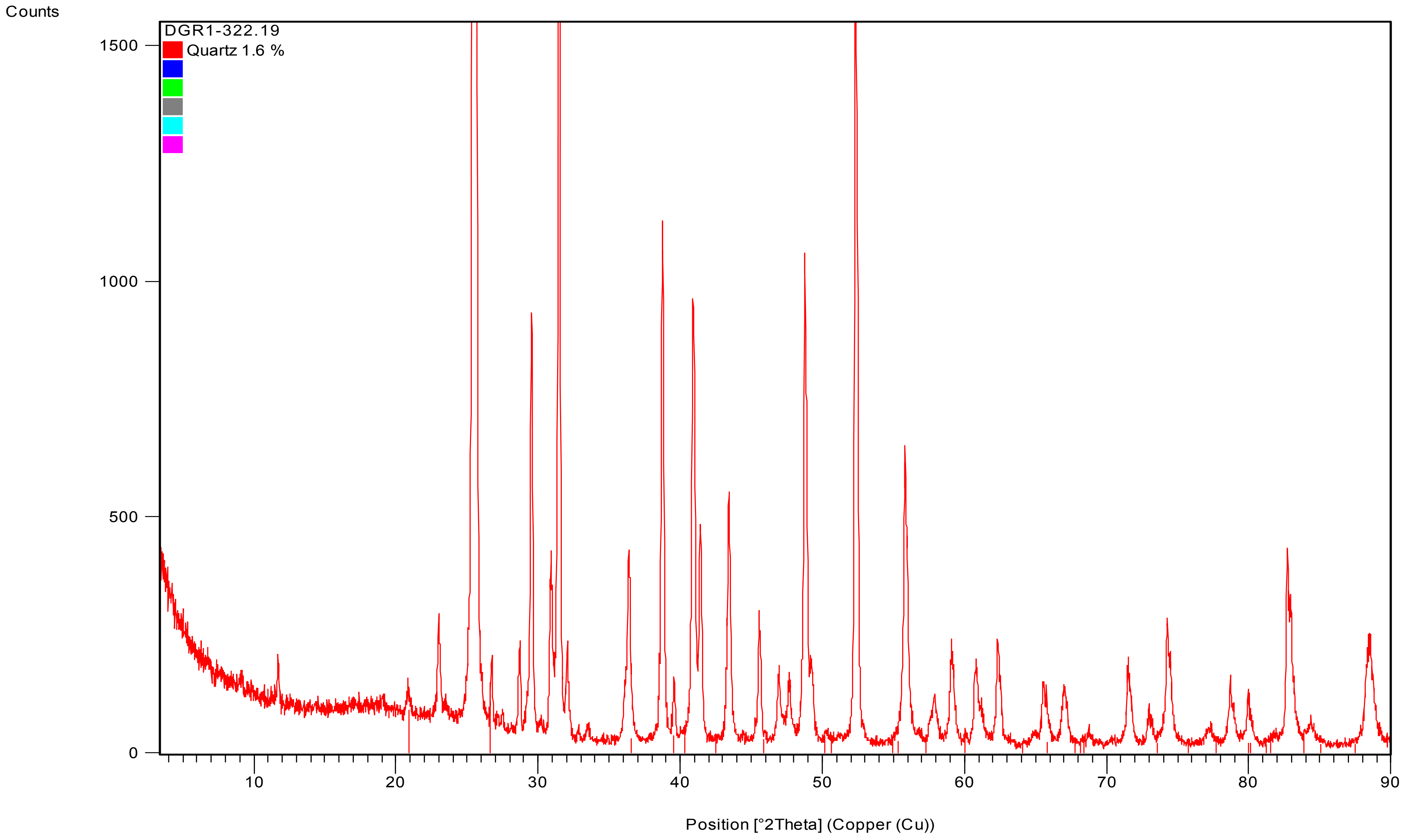

Counts
DGR1-322.19
Gypsum 2.2 %
1500
1000
500
0
10
20
30
40
50
60
70
80
90
Position [°2Theta] (Copper (Cu))

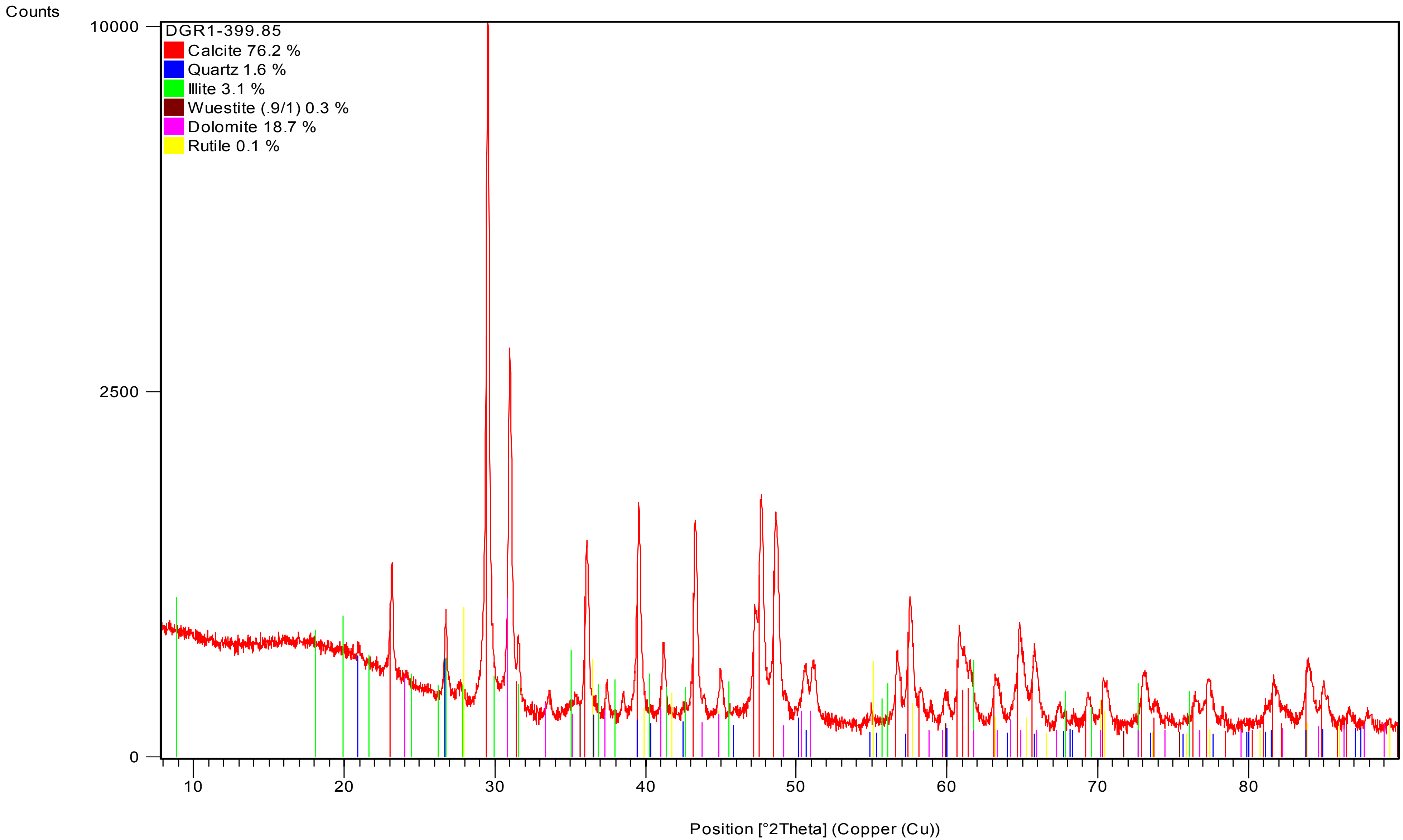

Counts
DGR1-322.19
Feldspar Strontium 0.3 %
1500
1000
500
0
10
20
30
40
50
60
70
80
90
Position [°2Theta] (Copper (Cu))

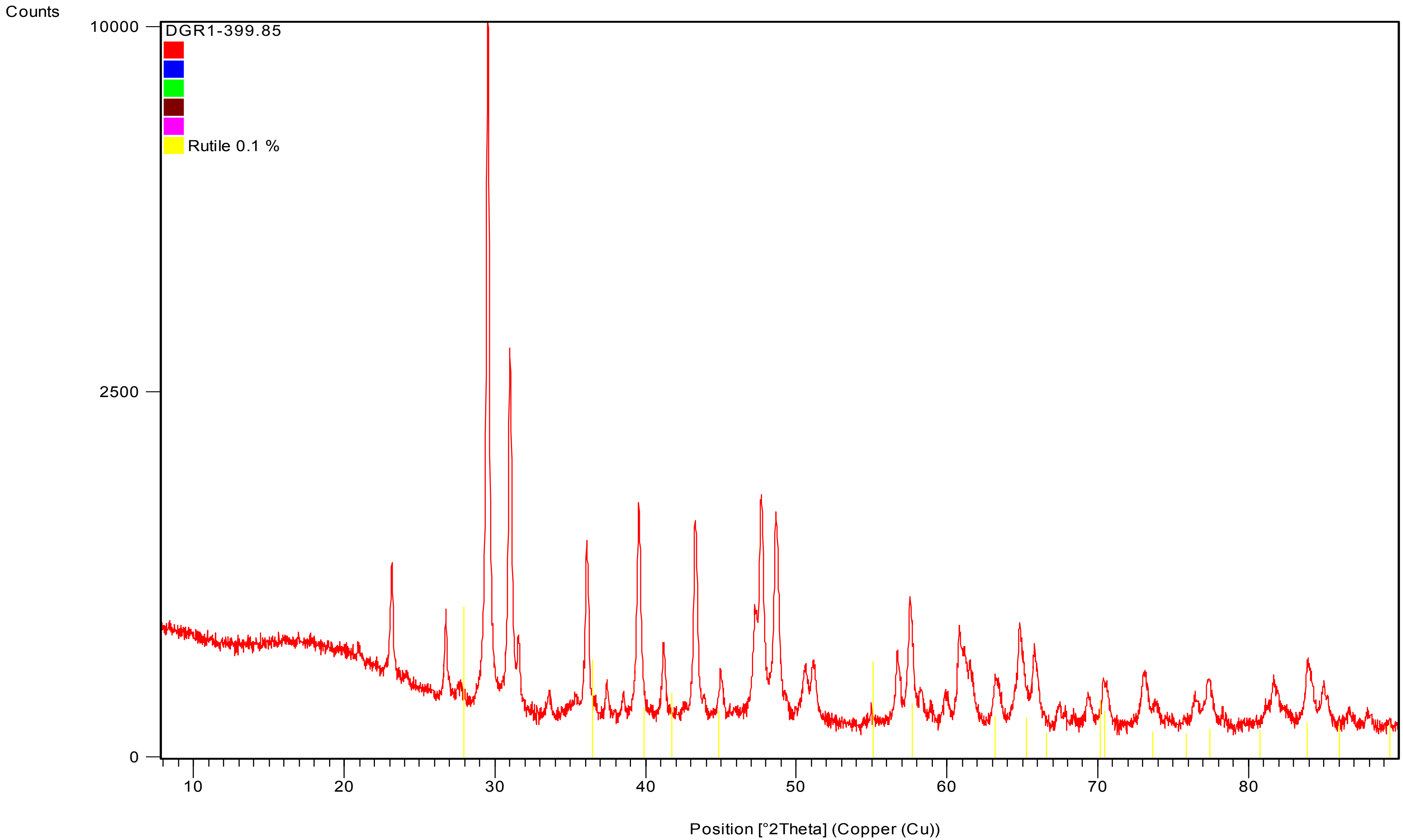

Counts
DGR1-322.19
Dolomite 3.4 %
1500
1000
500
0
10
20
30
40
50
60
70
80
90
Position [°2Theta] (Copper (Cu))

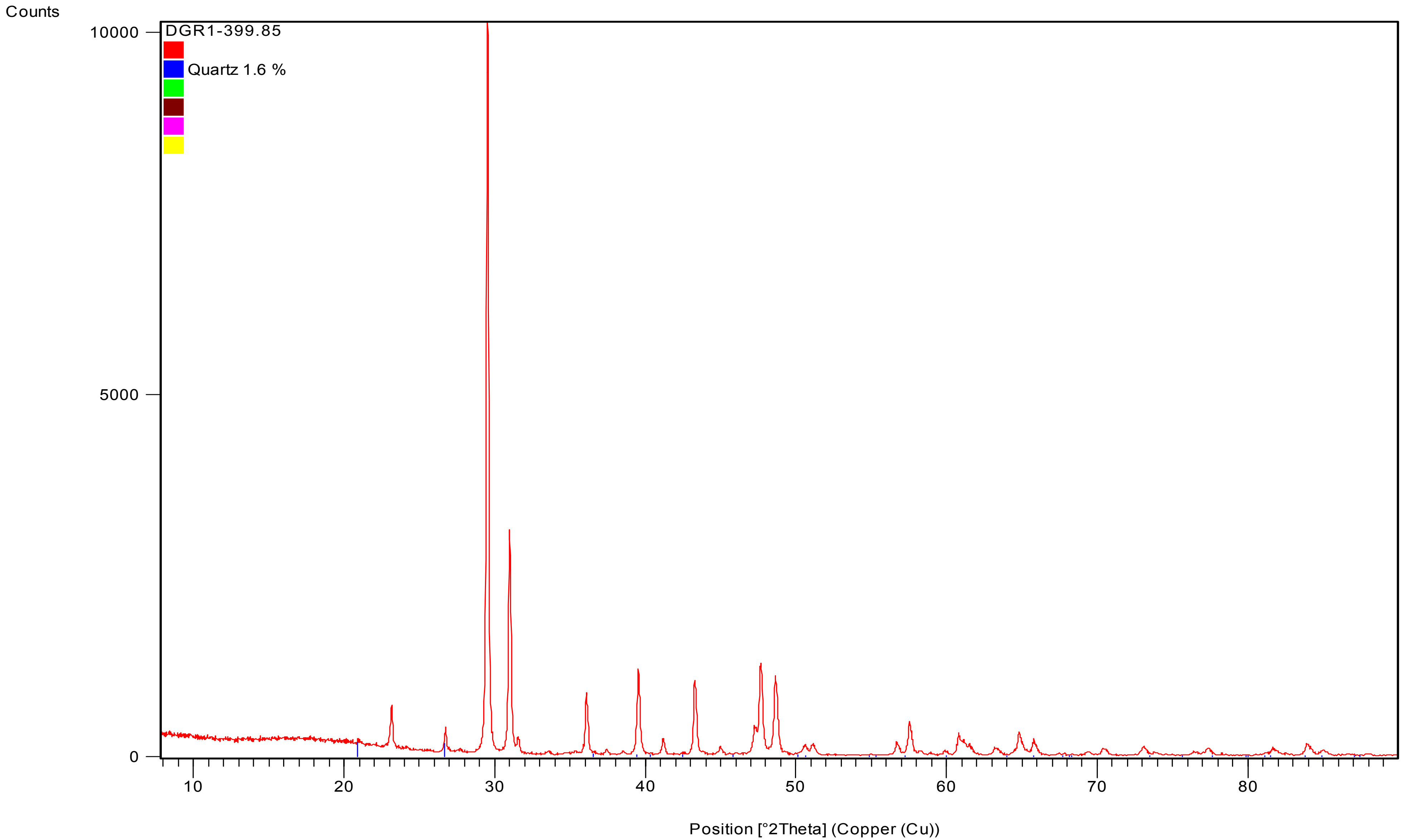

Counts
DGR1-322.19
Calcite 7.8 %
1500
1000
500
0
10
20
30
40
50
60
70
80
90
Position [°2Theta] (Copper (Cu))

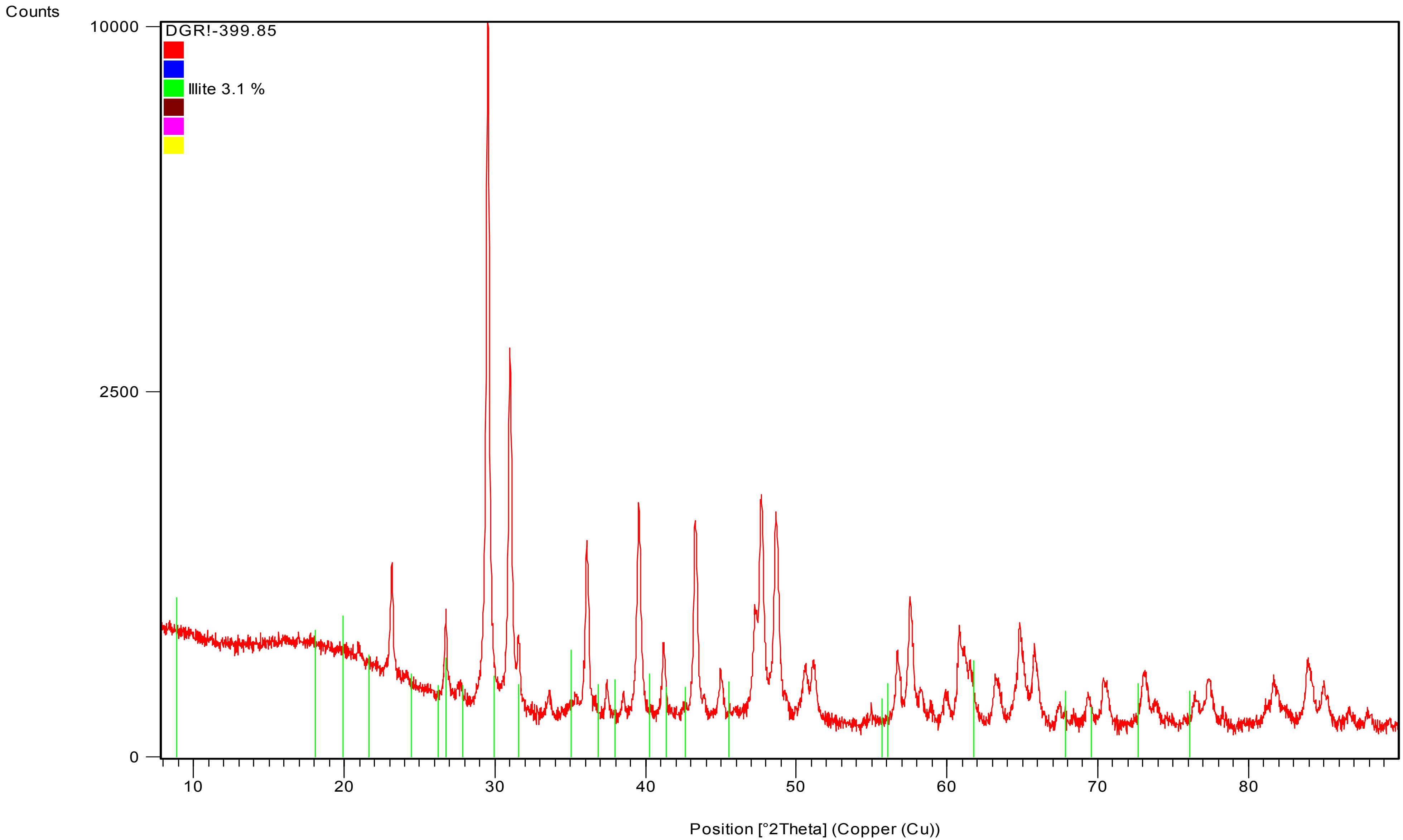

Counts
DGR1-322.19
Anhydrite 84.6 %
1500
1000
500
0
10
20
30
40
50
60
70
80
90
Position [°2Theta] (Copper (Cu))

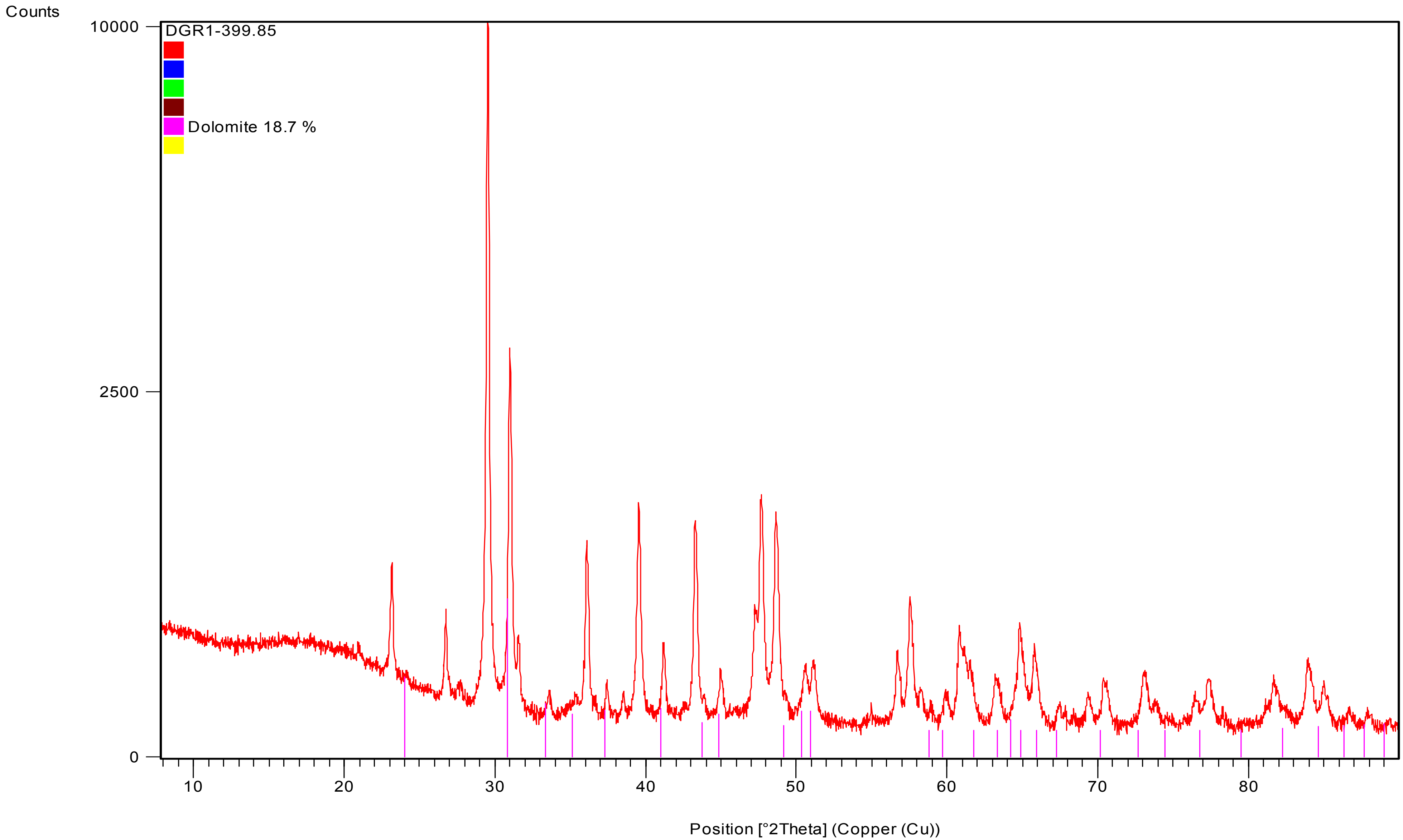

Counts
DGR1-322.19
Quartz 1.6 %
1500
1000
500
0
10
20
30
40
50
60
70
80
90
Position [°2Theta] (Copper (Cu))

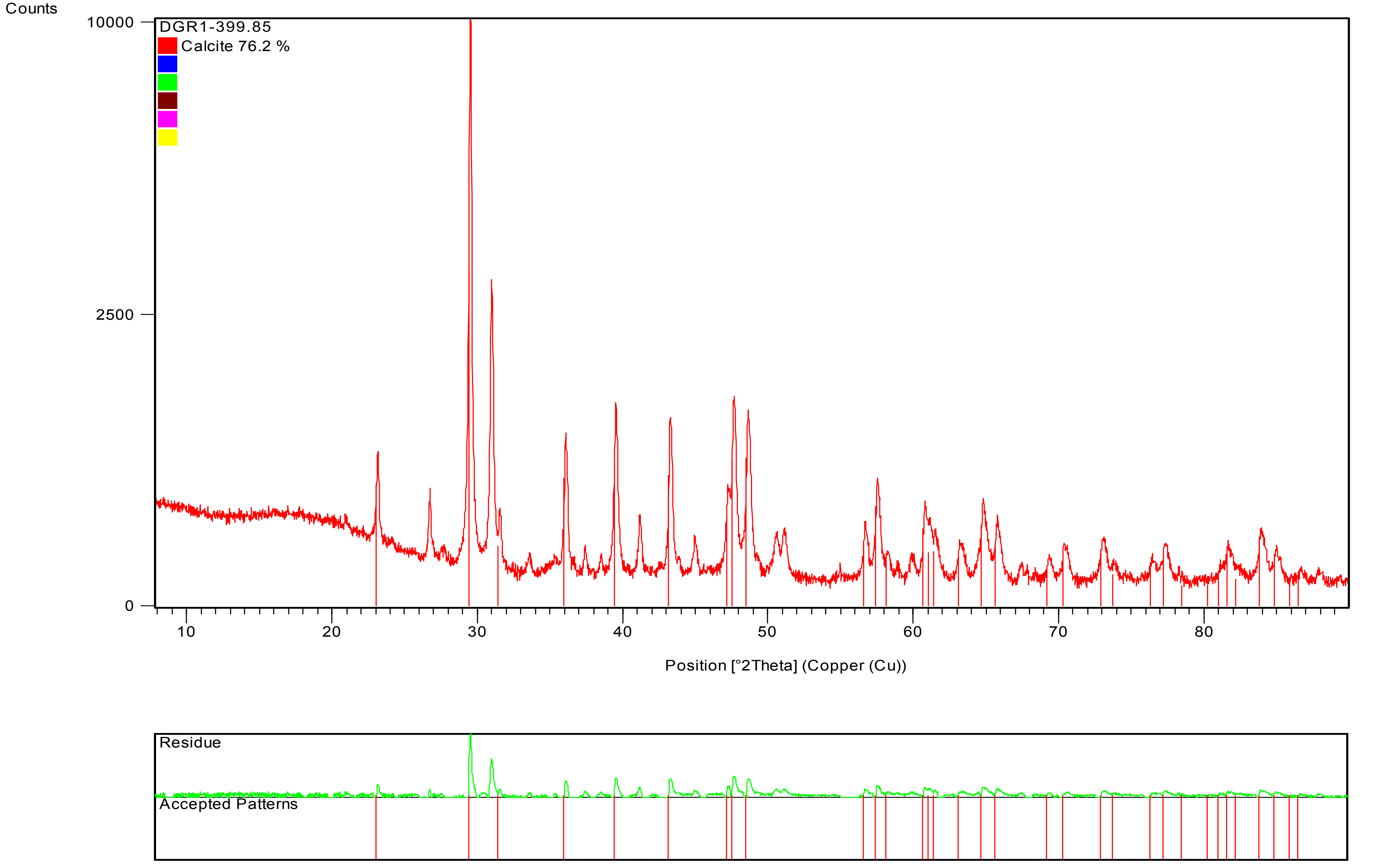

Counts
10000
2500
0
DGR1-399.85
Calcite 76.2 %
Quartz 1.6 %
Illite 3.1 %
Wuestite (.9/1) 0.3 %
Dolomite 18.7 %
Rutile 0.1 %
10
20
30
40
50
60
70
80
Position [°2Theta] (Copper (Cu))

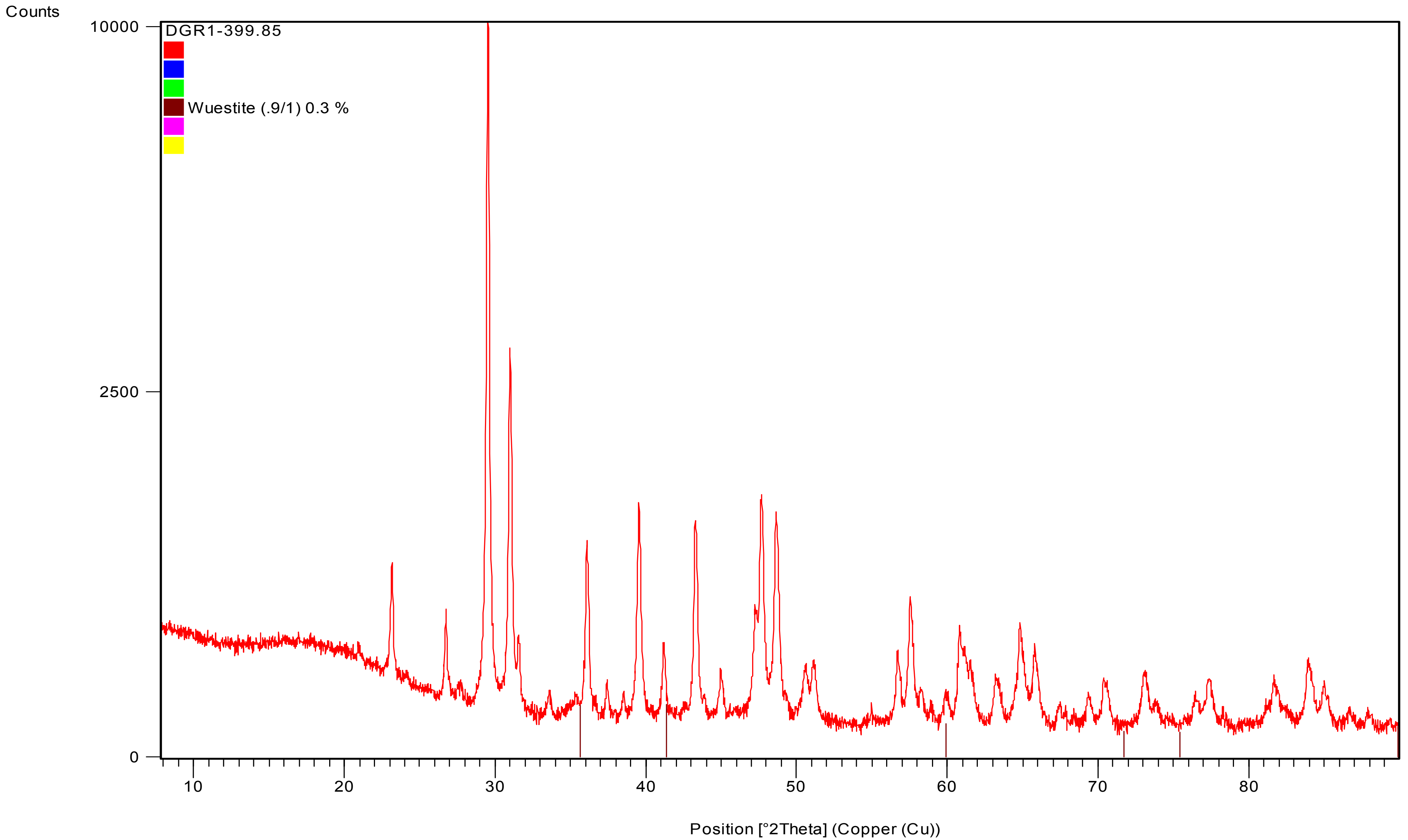

Counts
10000
2500
0
DGR1-399.85
Rutile 0.1 %
10
20
30
40
50
60
70
80
Position [°2Theta] (Copper (Cu))


Counts
10000
5000
0
DGR1-399.85
Quartz 1.6 %
10
20
30
40
50
60
70
80
Position [°2Theta] (Copper (Cu))

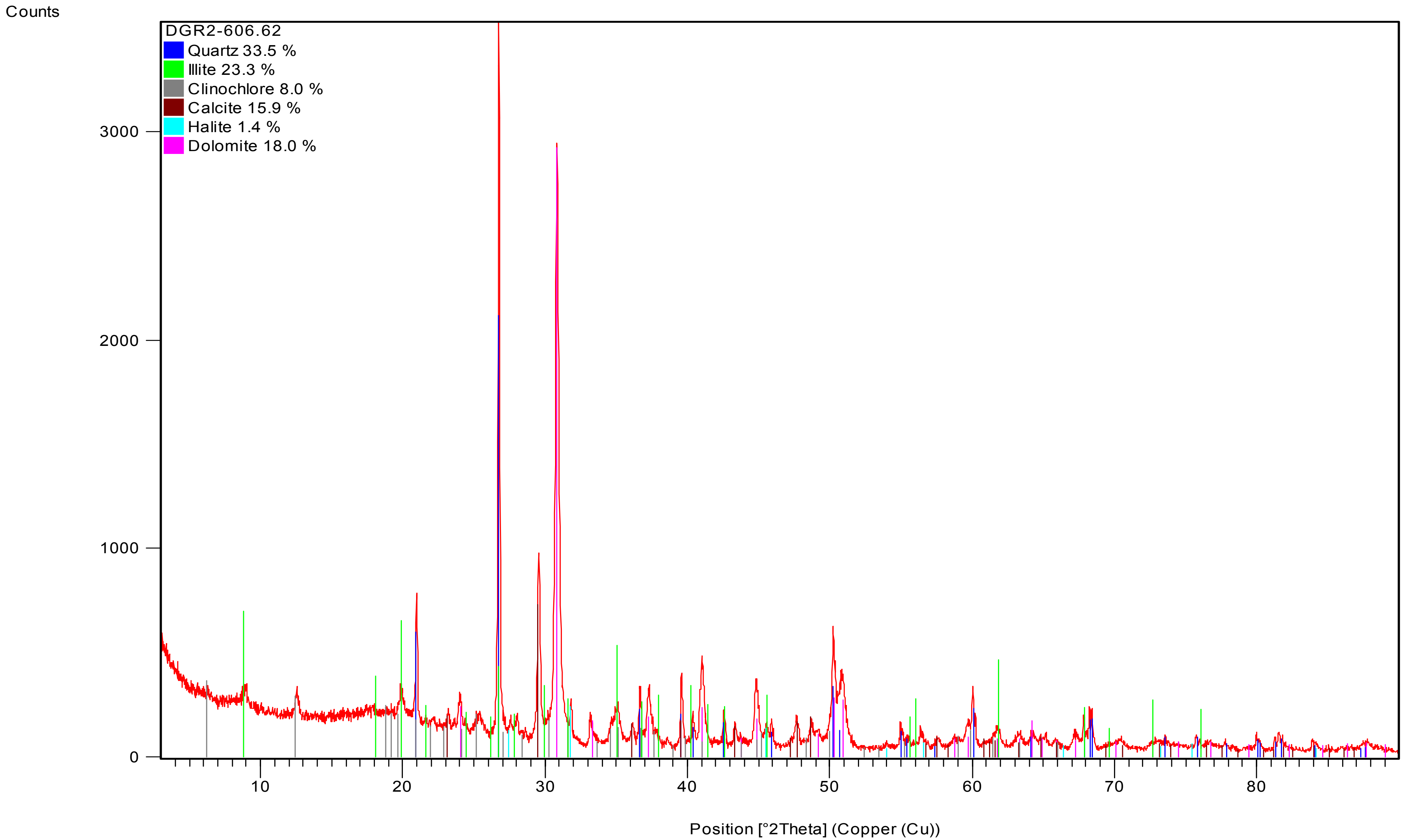

Counts
10000
2500
0
DGR!-399.85
Illite 3.1 %
10
20
30
40
50
60
70
80
Position [°2Theta] (Copper (Cu))

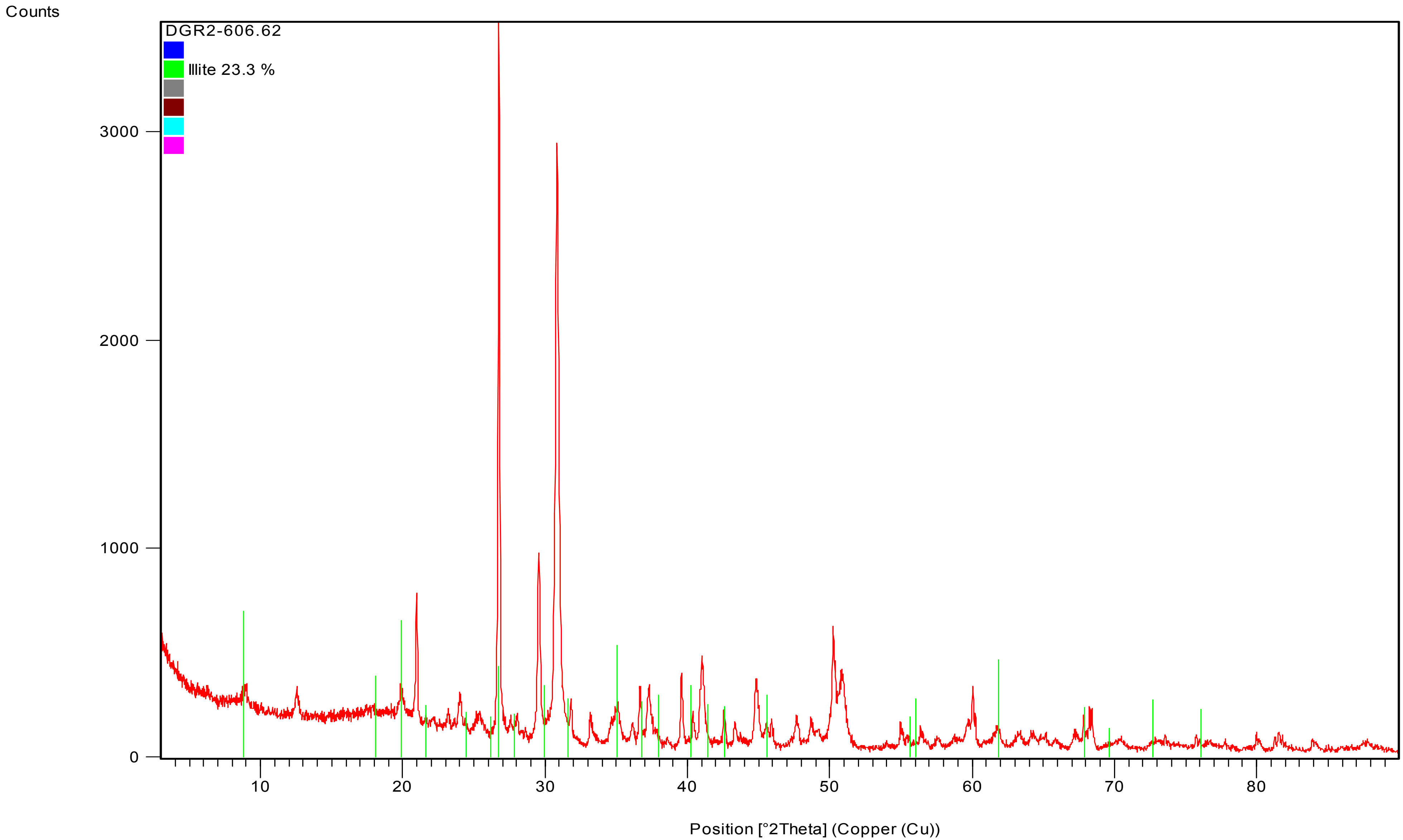

Counts
10000
2500
0
DGR1-399.85
Dolomite 18.7 %
10
20
30
40
50
60
70
80
Position [°2Theta] (Copper (Cu))

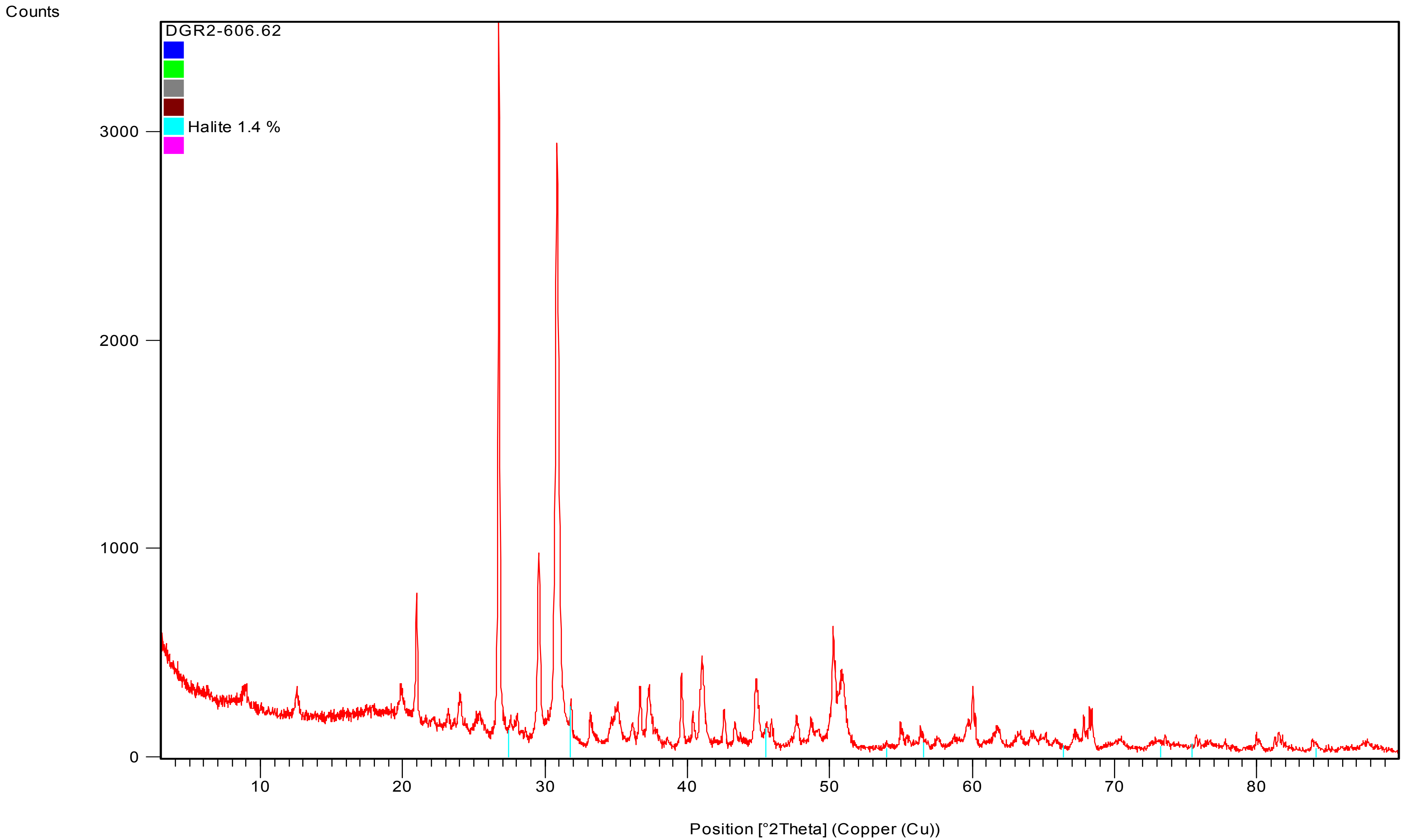

Counts
10000
2500
0
DGR1-399.85
Calcite 76.2 %
10
20
30
40
50
60
70
80
Position [°2Theta] (Copper (Cu))
Residue
Accepted Patterns

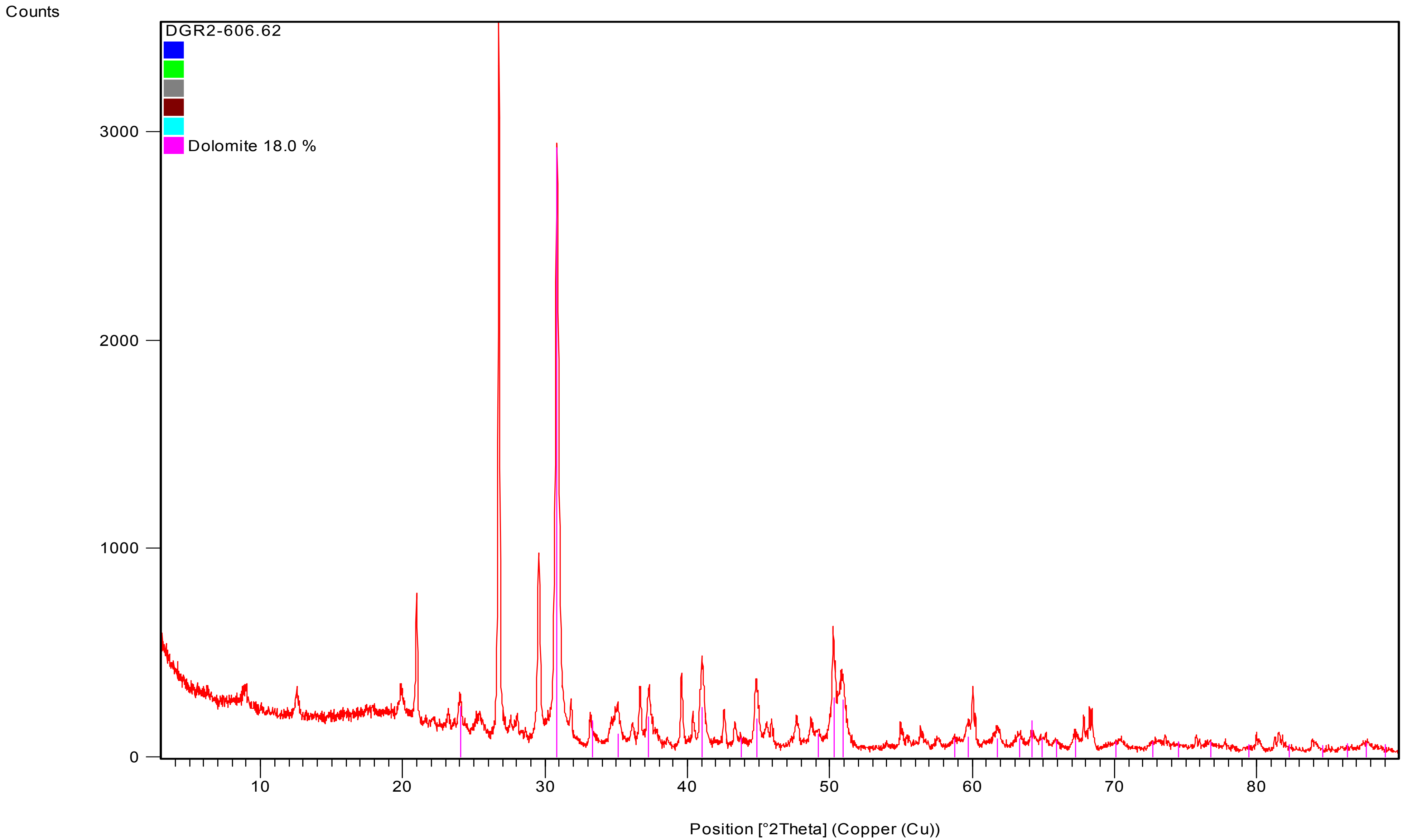


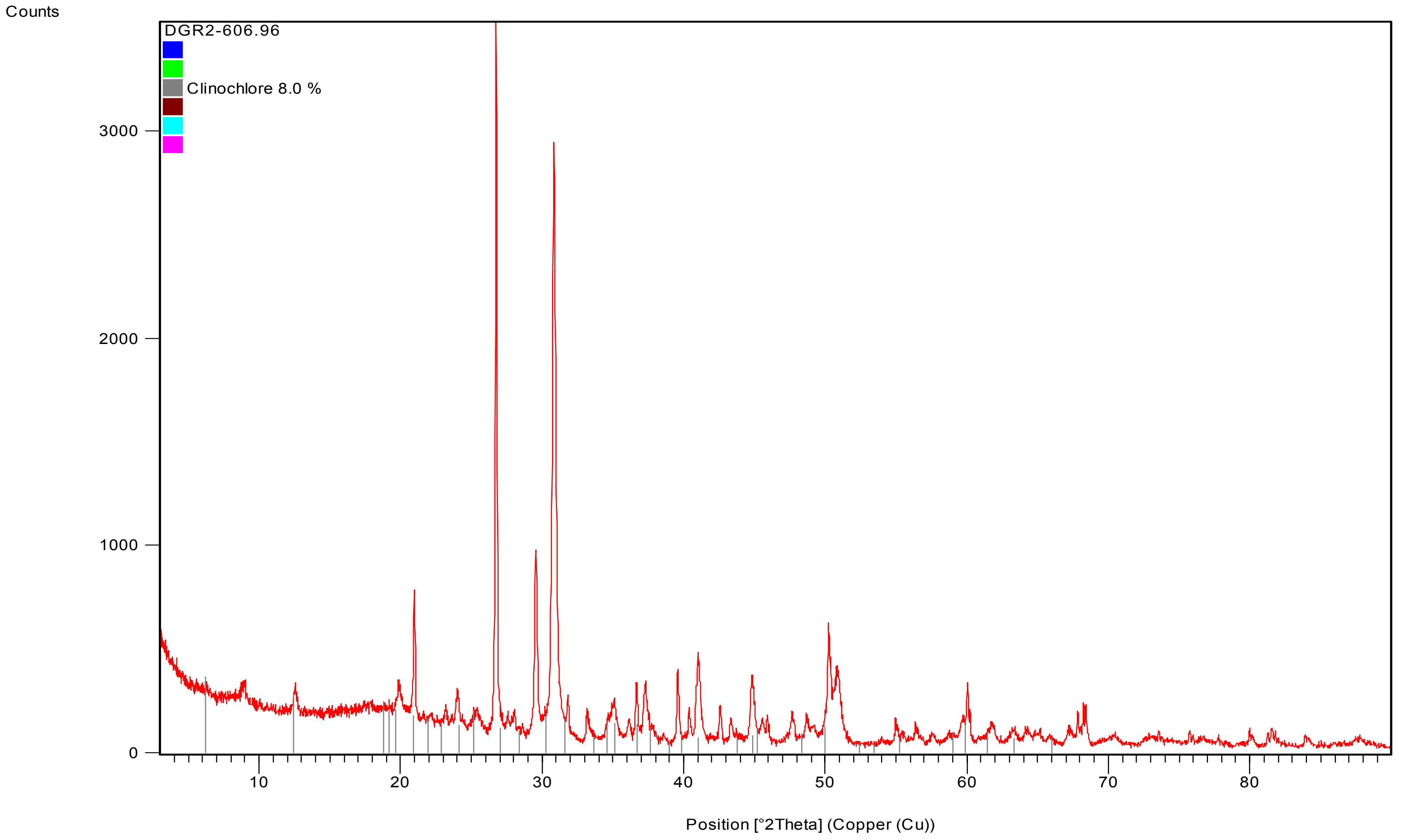
Counts
10000
2500
0
DGR1-399.85
Wuestite (.9/1) 0.3 %
10
20
30
40
50
60
70
80
Position [°2Theta] (Copper (Cu))

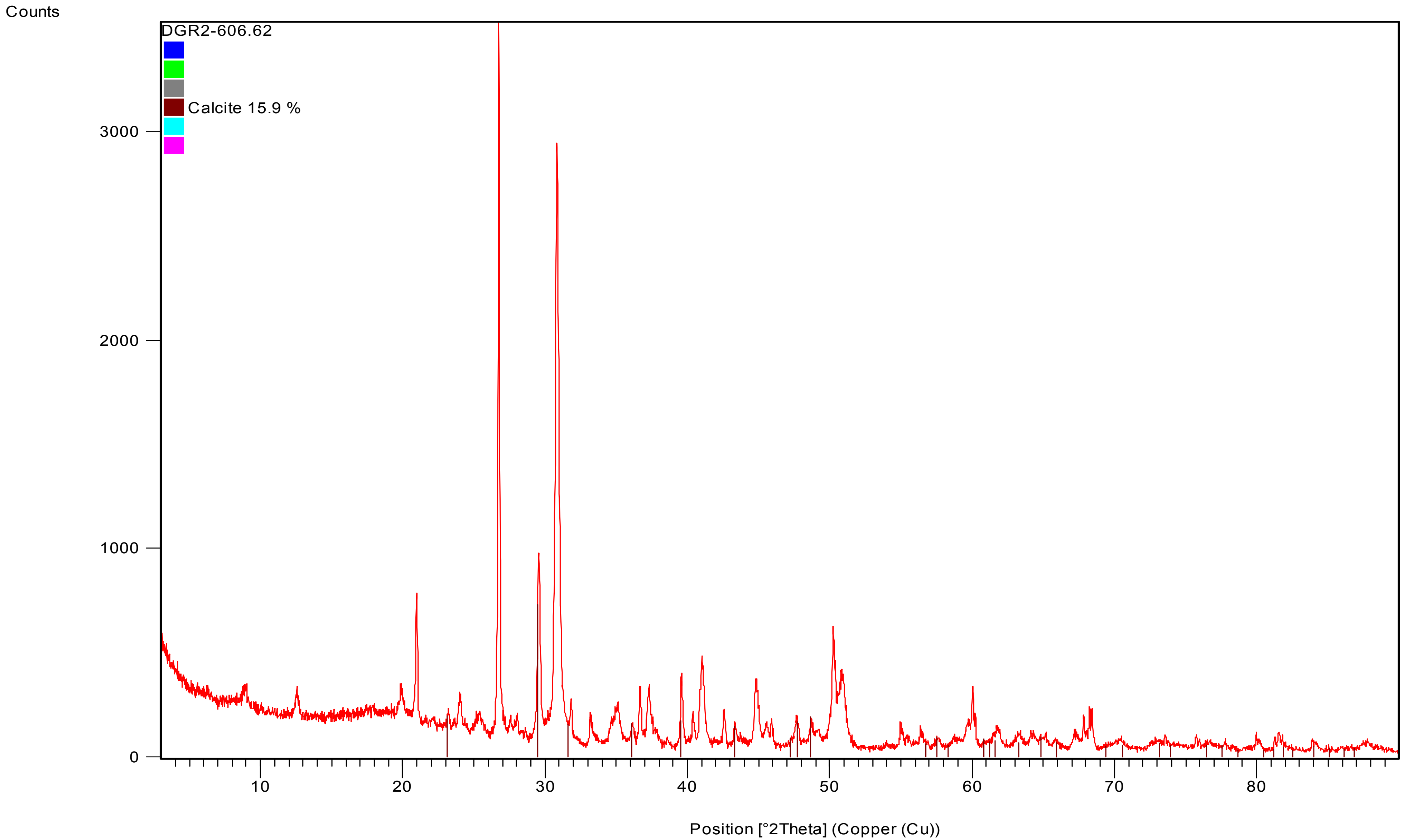

Counts
DGR2-606.62
Quartz 33.5 %
Illite 23.3 %
Clinochlore 8.0 %
Calcite 15.9 %
Halite 1.4 %
Dolomite 18.0 %
3000
2000
1000
0
10
20
30
40
50
60
70
80
Position [°2Theta] (Copper (Cu))


Counts
DGR2-606.62
Illite 23.3 %
3000
2000
1000
0
10
20
30
40
50
60
70
80
Position [°2Theta] (Copper (Cu))

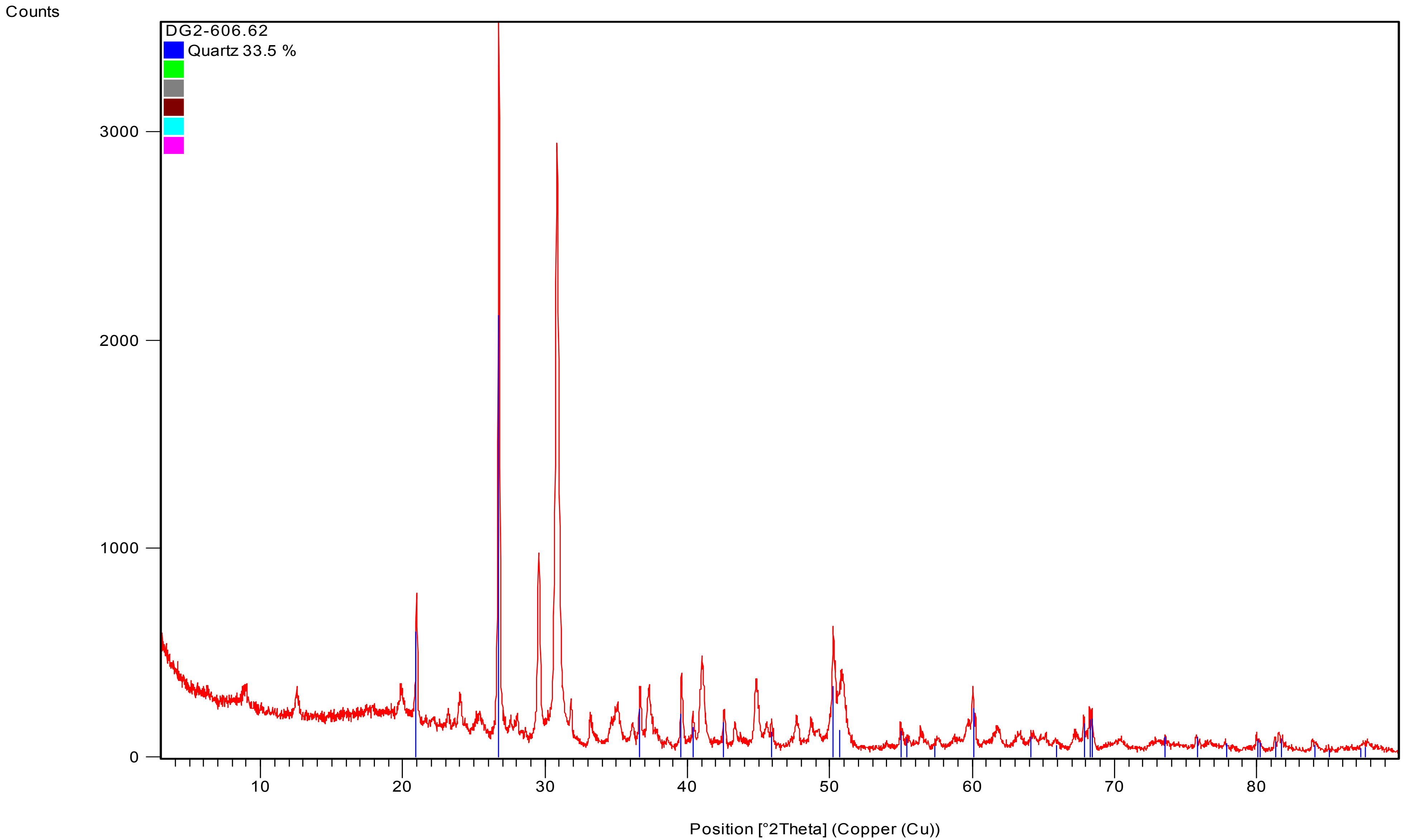

Counts
DGR2-606.62
Halite 1.4 %
3000
2000
1000
0
10
20
30
40
50
60
70
80
Position [°2Theta] (Copper (Cu))


Counts
DGR2-606.62
Dolomite 18.0 %
3000
2000
1000
0
10
20
30
40
50
60
70
80
Position [°2Theta] (Copper (Cu))

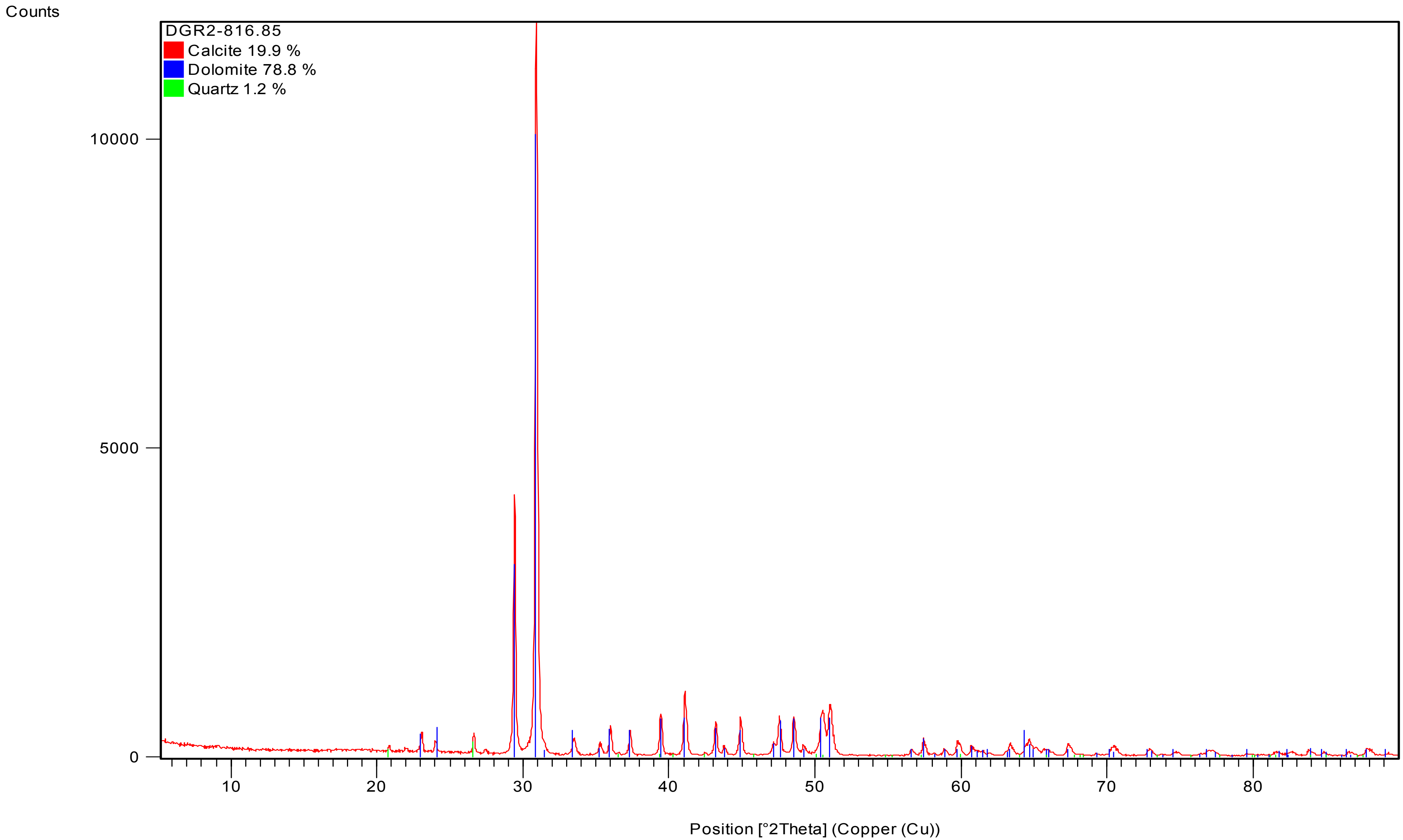

Counts
DGR2-606.96
Clinochlore 8.0 %
3000
2000
1000
0
10
20
30
40
50
60
70
80
Position [°2Theta] (Copper (Cu))



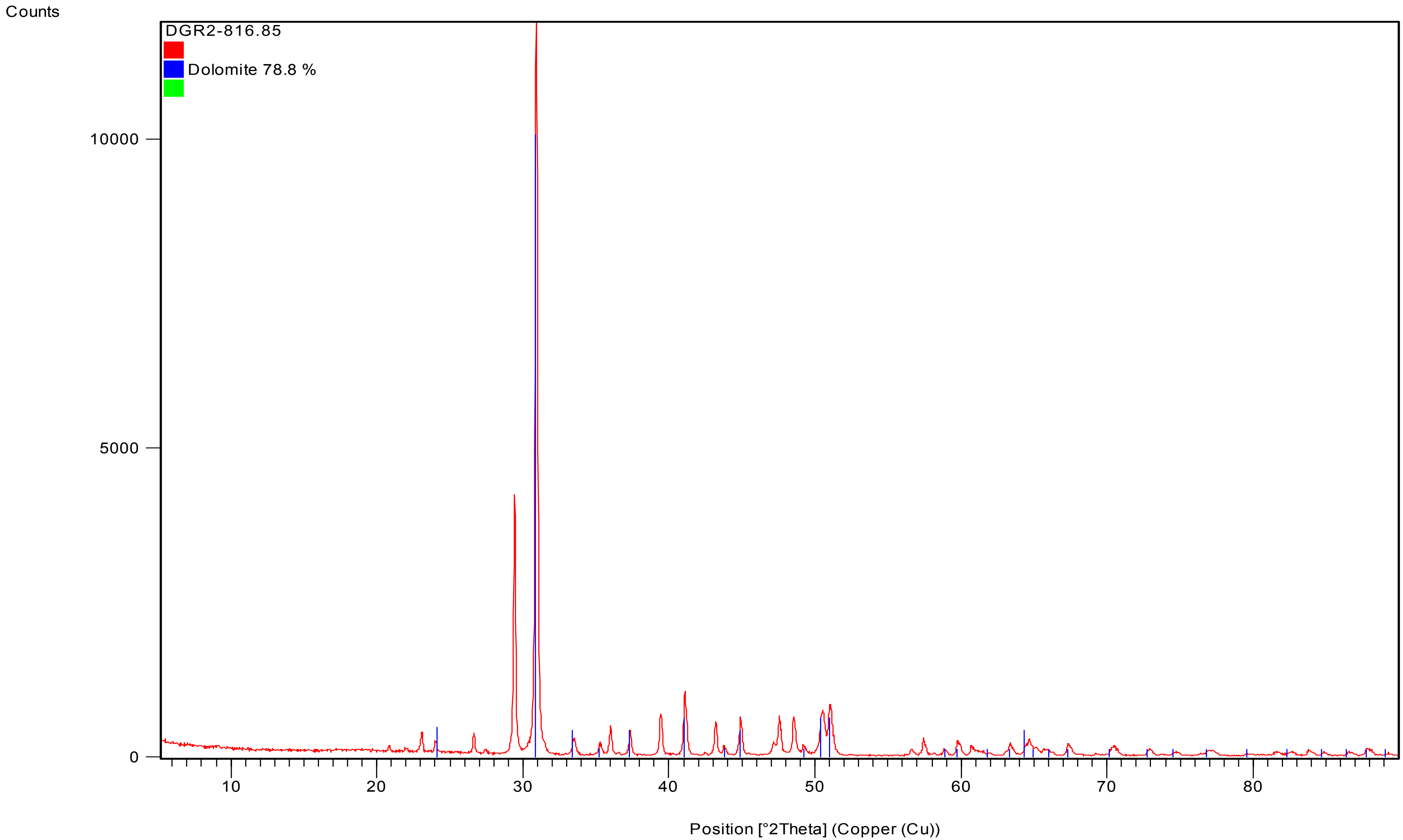
Counts
DGR2-606.62
Calcite 15.9 %
3000
2000
1000
0
10
20
30
40
50
60
70
80
Position [°2Theta] (Copper (Cu))

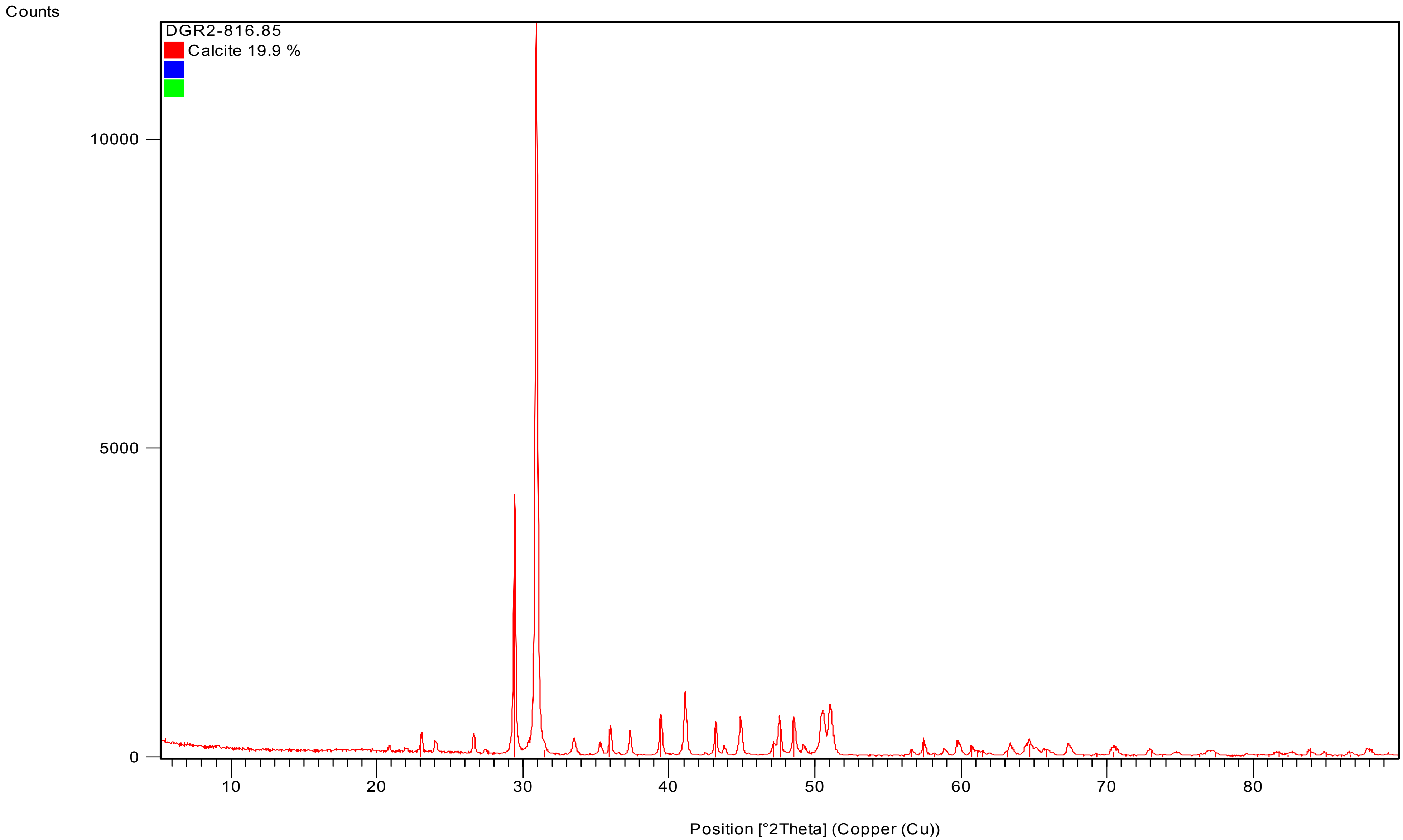


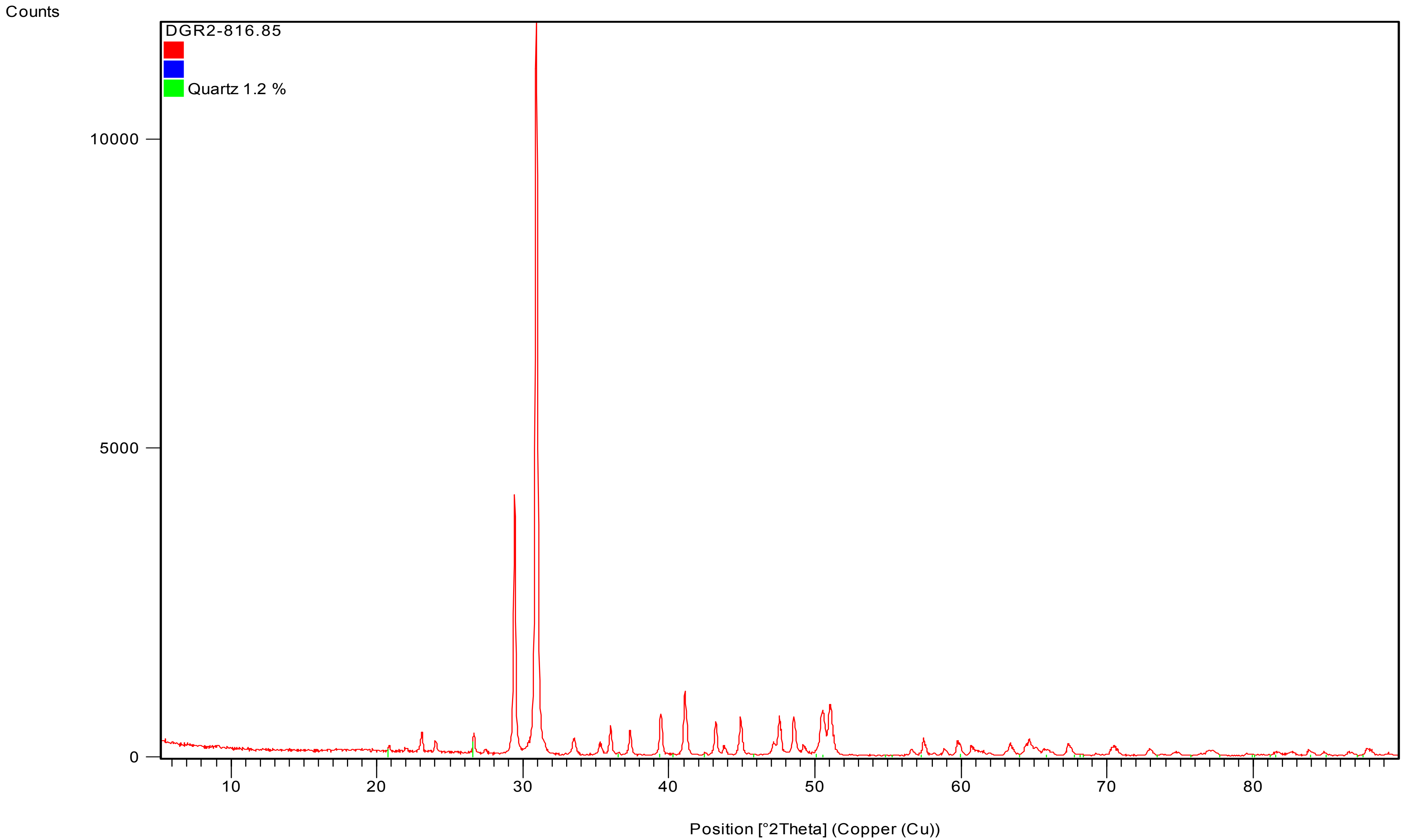
Counts
DG2-606.62
Quartz 33.5 %
3000
2000
1000
0
10
20
30
40
50
60
70
80
Position [°2Theta] (Copper (Cu))

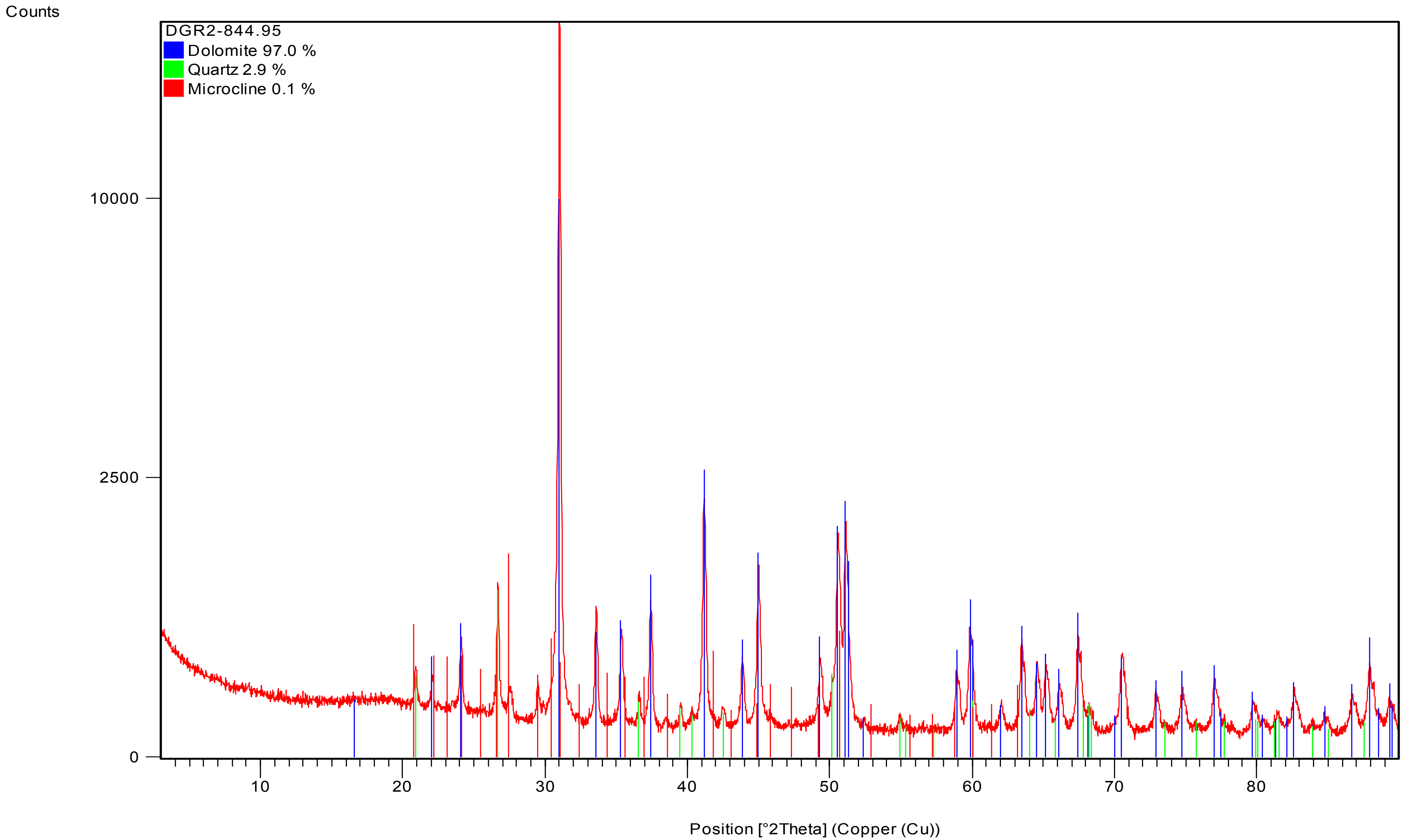


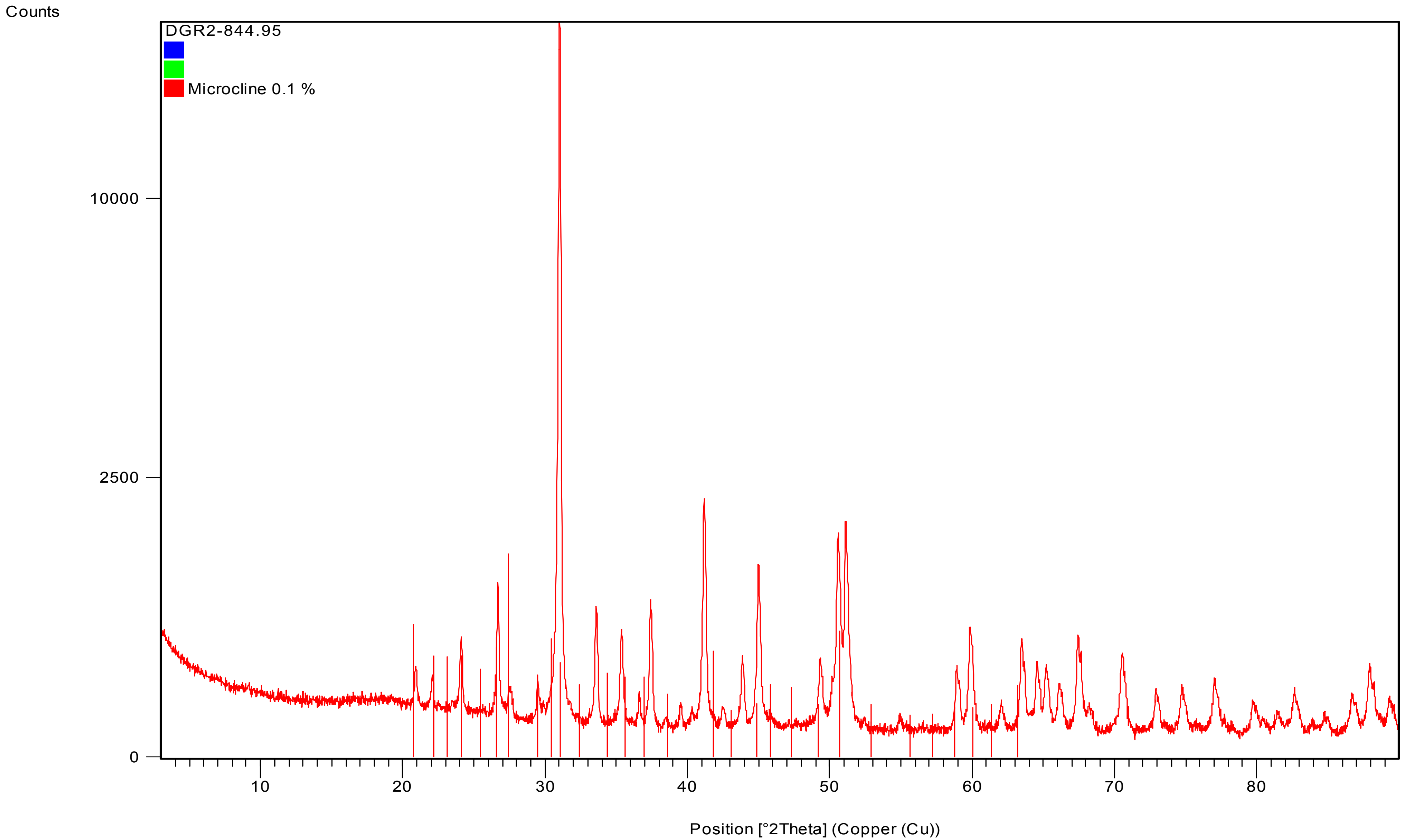
Counts
DGR2-816.85
Calcite 19.9 %
Dolomite 78.8 %
Quartz 1.2 %
10000
5000
0
10
20
30
40
50
60
70
80
Position [°2Theta] (Copper (Cu))


Counts
DGR2-816.85
Dolomite 78.8 %
10000
5000
0
10
20
30
40
50
60
70
80
Position [°2Theta] (Copper (Cu))

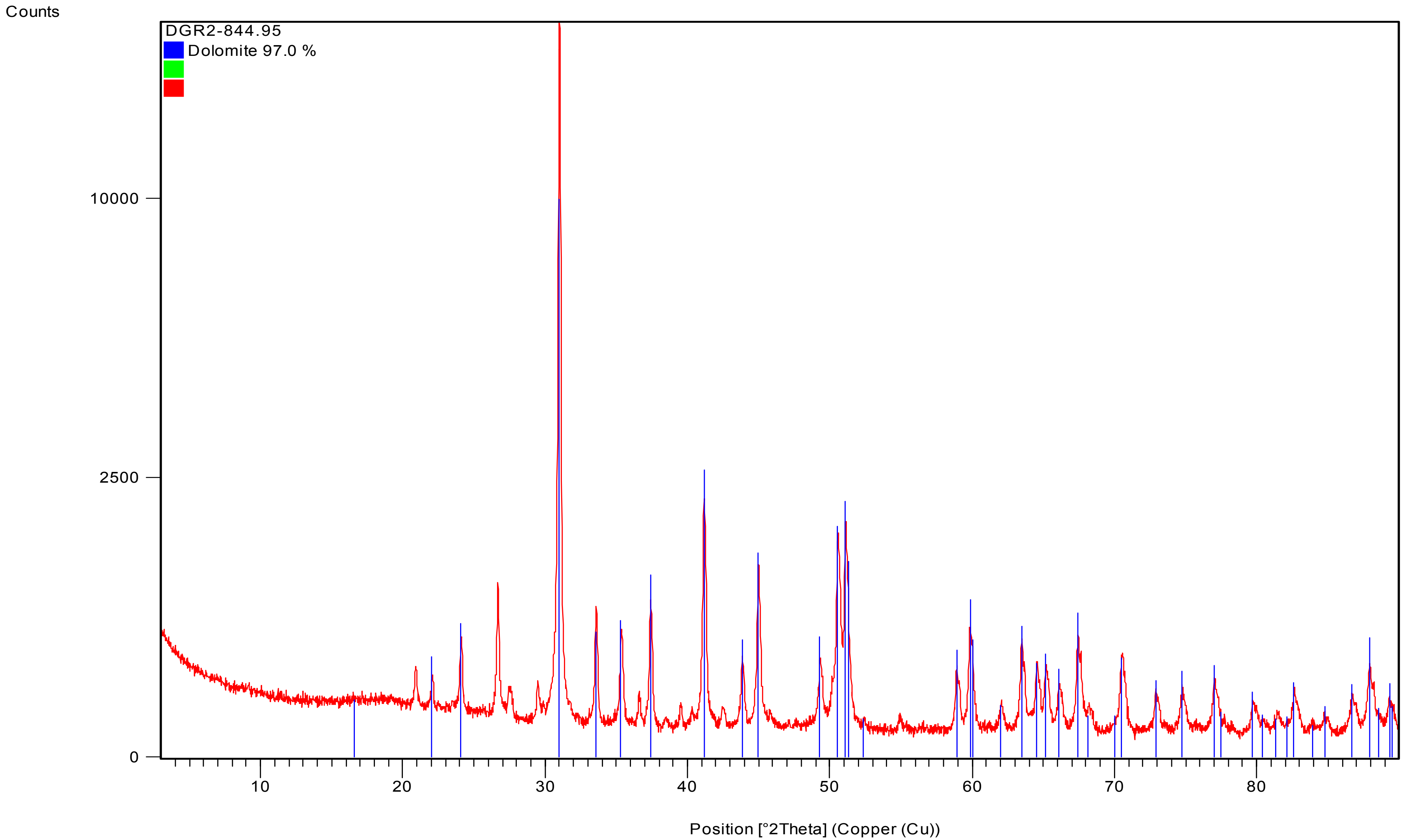

Counts
DGR2-816.85
Calcite 19.9 %
10000
5000
0
10
20
30
40
50
60
70
80
Position [°2Theta] (Copper (Cu))

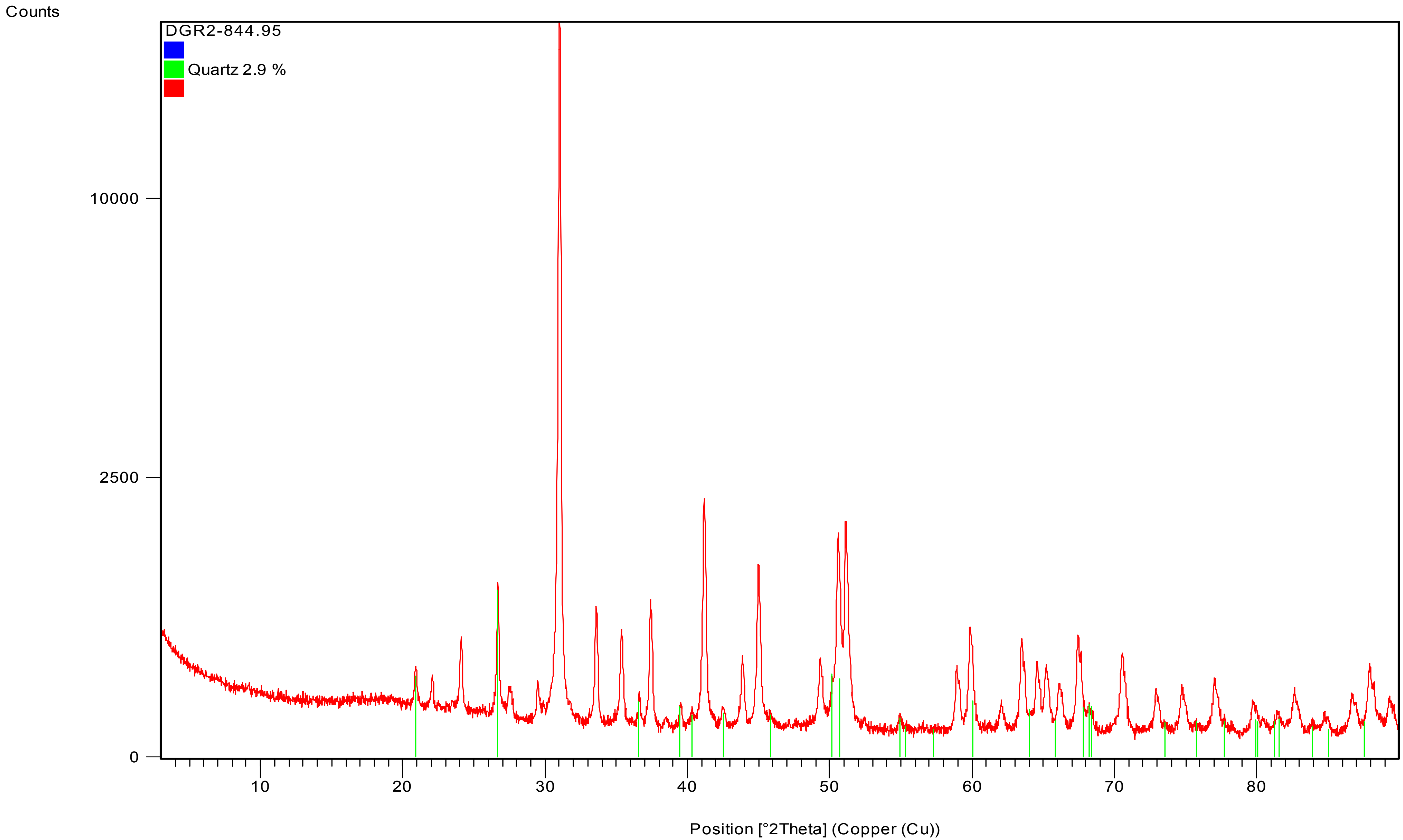

Counts
DGR2-816.85
Quartz 1.2 %
10000
5000
0
10
20
30
40
50
60
70
80
Position [°2Theta] (Copper (Cu))


Counts
DGR2-844.95
Dolomite 97.0 %
Quartz 2.9 %
Microcline 0.1 %
10000
2500
0
10
20
30
40
50
60
70
80
Position [°2Theta] (Copper (Cu))



Counts
DGR2-844.95
Microcline 0.1 %
10000
2500
0
10
20
30
40
50
60
70
80
Position [°2Theta] (Copper (Cu))

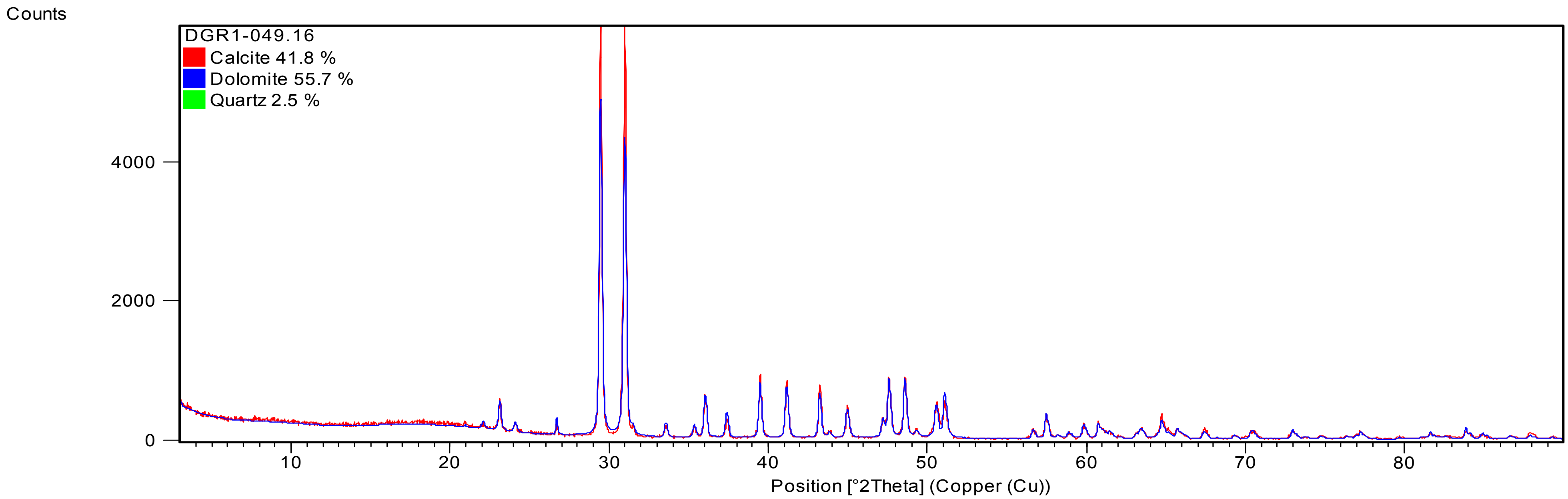

Counts
DGR2-844.95
Dolomite 97.0 %
10000
2500
0
10
20
30
40
50
60
70
80
Position [°2Theta] (Copper (Cu))

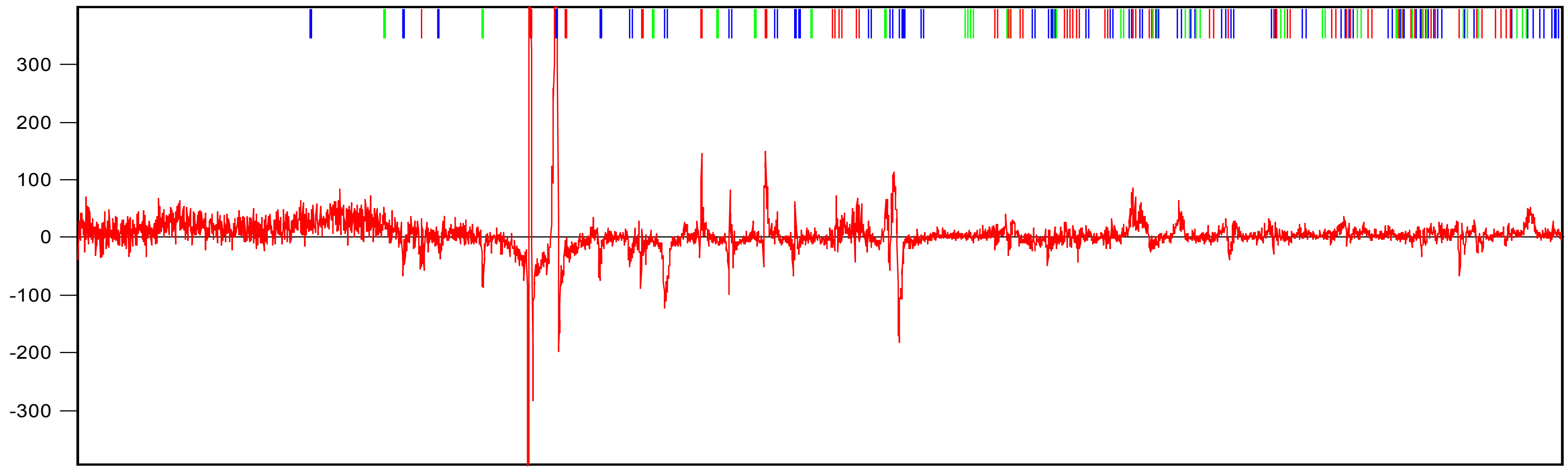


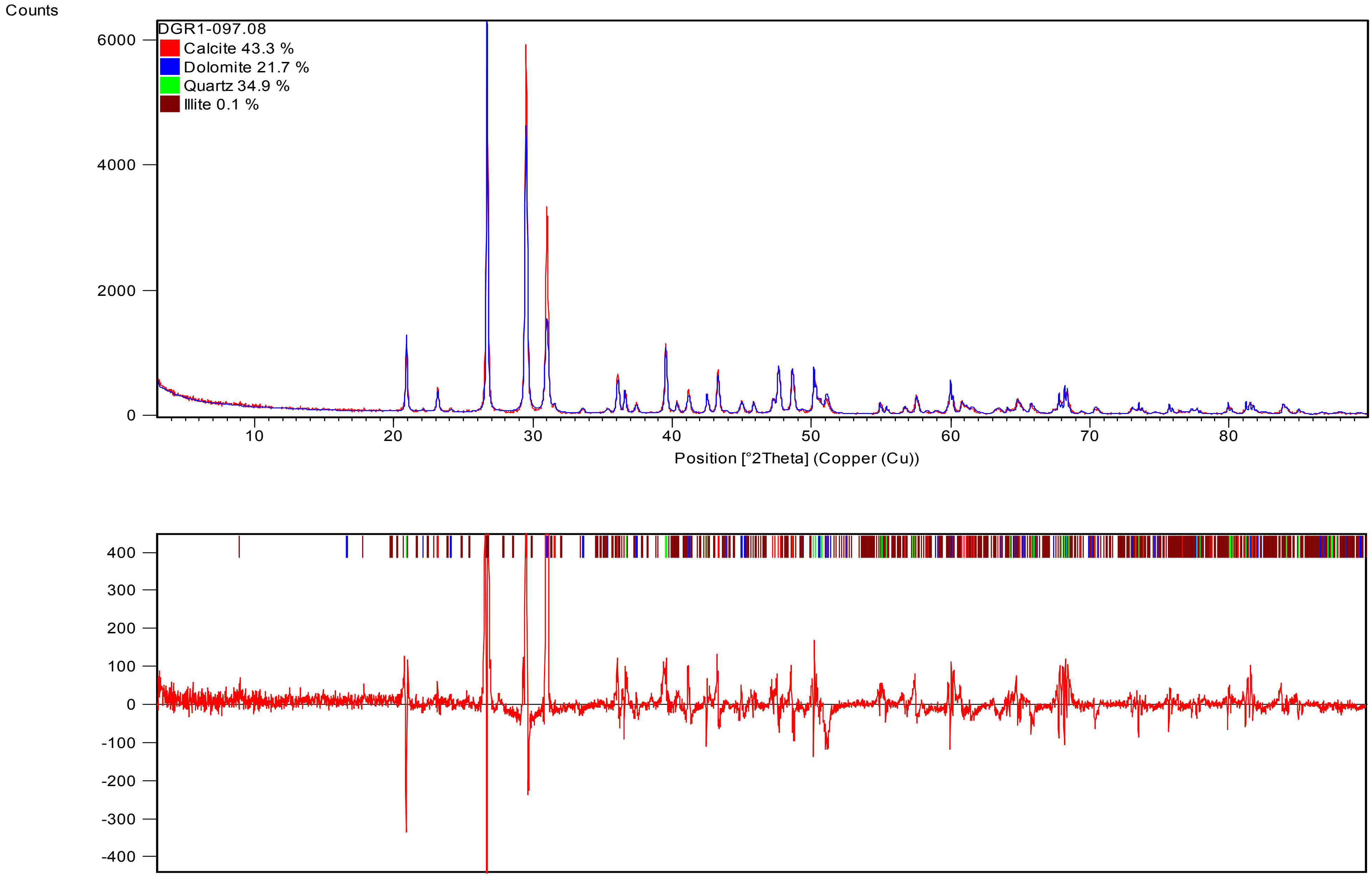
Counts
DGR2-844.95
Quartz 2.9 %
10000
2500
0
10
20
30
40
50
60
70
80
Position [°2Theta] (Copper (Cu))

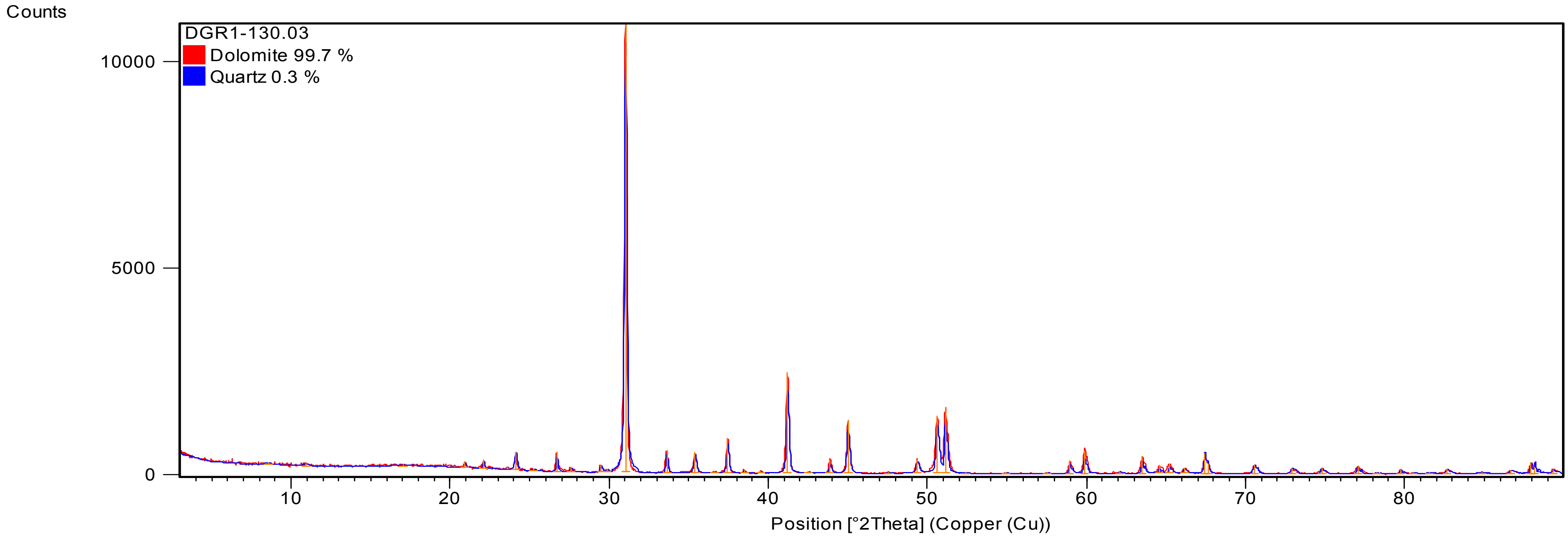
APPENDIX B

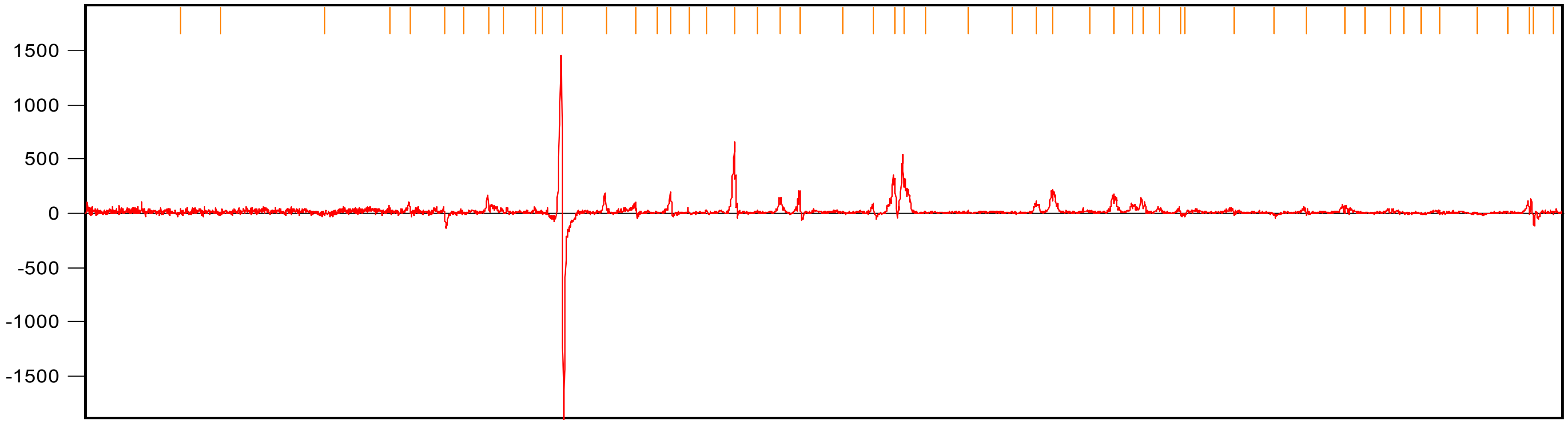
Rietveld Analysis of X-Ray Powder Diffractograms for all DGR-1 and DGR-2 Core Samples

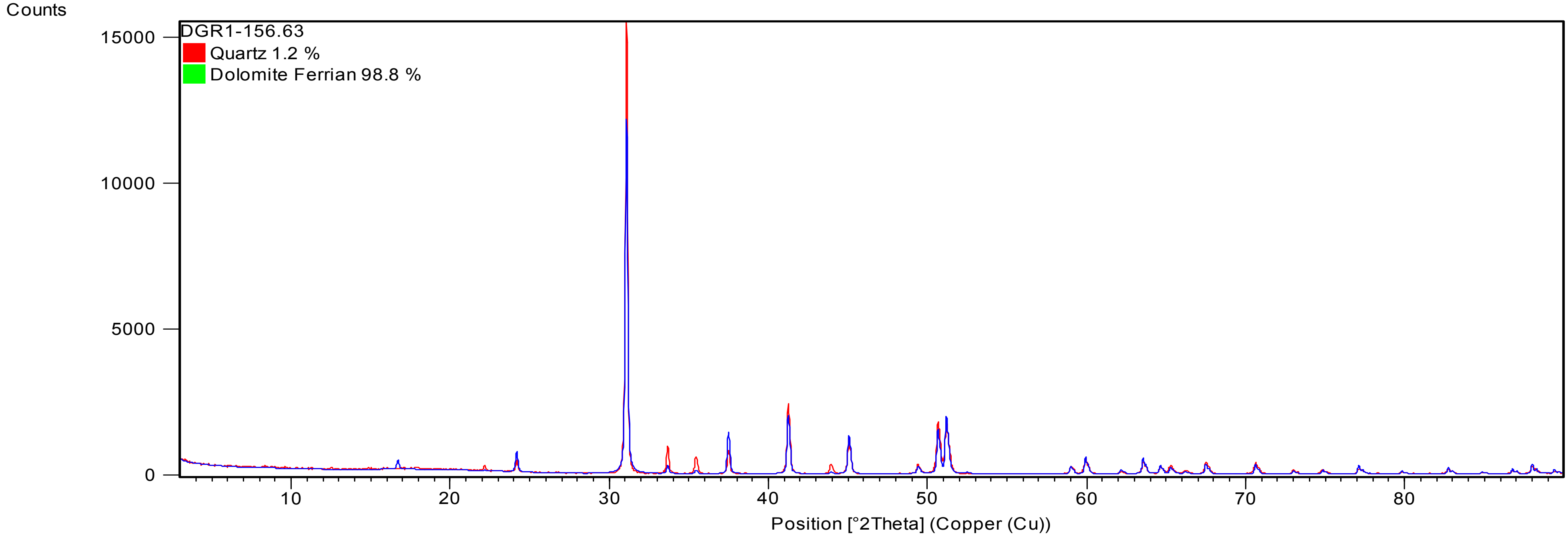

Counts
DGR1-049.16
Calcite 41.8 %
Dolomite 55.7 %
Quartz 2.5 %
4000
2000
0
10
20
30
40
50
60
70
80
Position [°2Theta] (Copper (Cu))

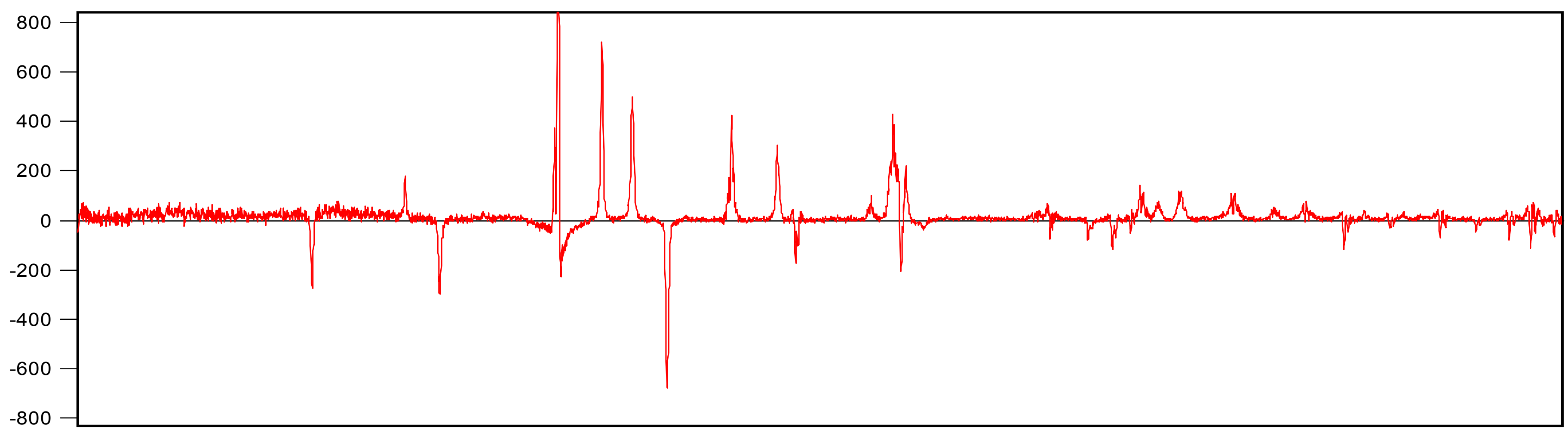

300
200
100
0
-100
-200
-300

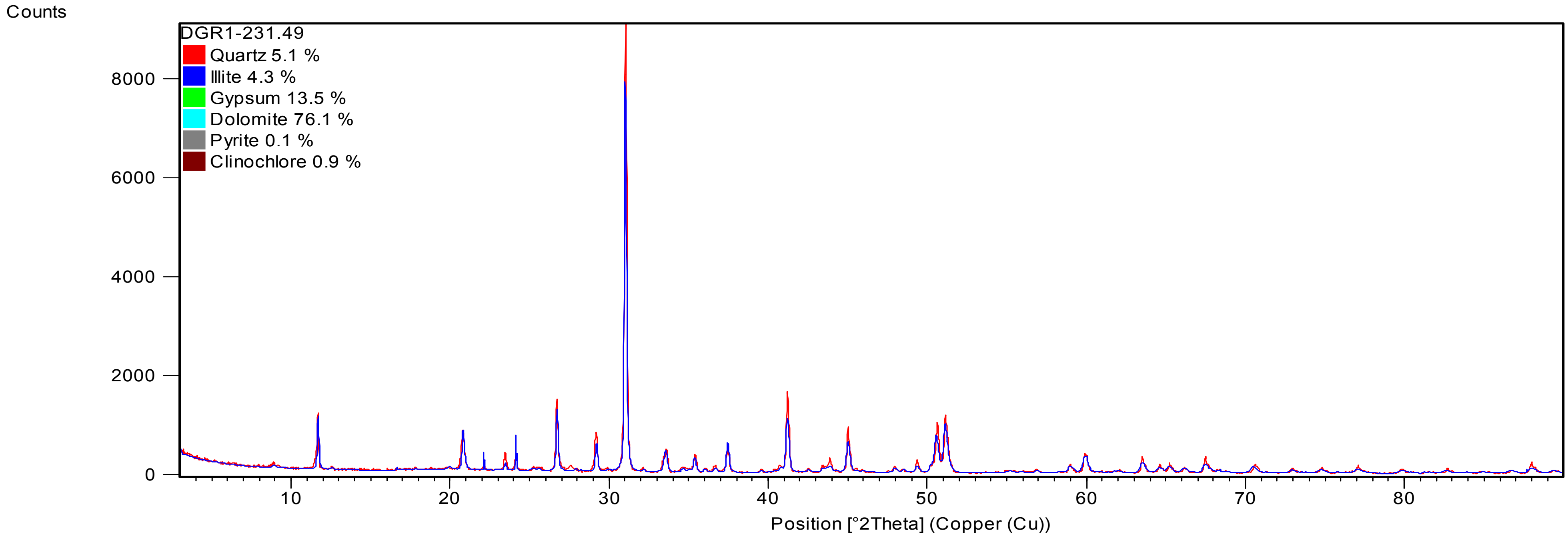

Counts
DGR1-097.08
Calcite 43.3 %
Dolomite 21.7 %
Quartz 34.9 %
Illite 0.1 %
6000
4000
2000
0
10
20
30
40
50
60
70
80
Position [°2Theta] (Copper (Cu))
400
300
200
100
0
-100
-200
-300
-400


Counts
DGR1-130.03
Dolomite 99.7 %
Quartz 0.3 %
10000
5000
0
10
20
30
40
50
60
70
80
Position [°2Theta] (Copper (Cu))

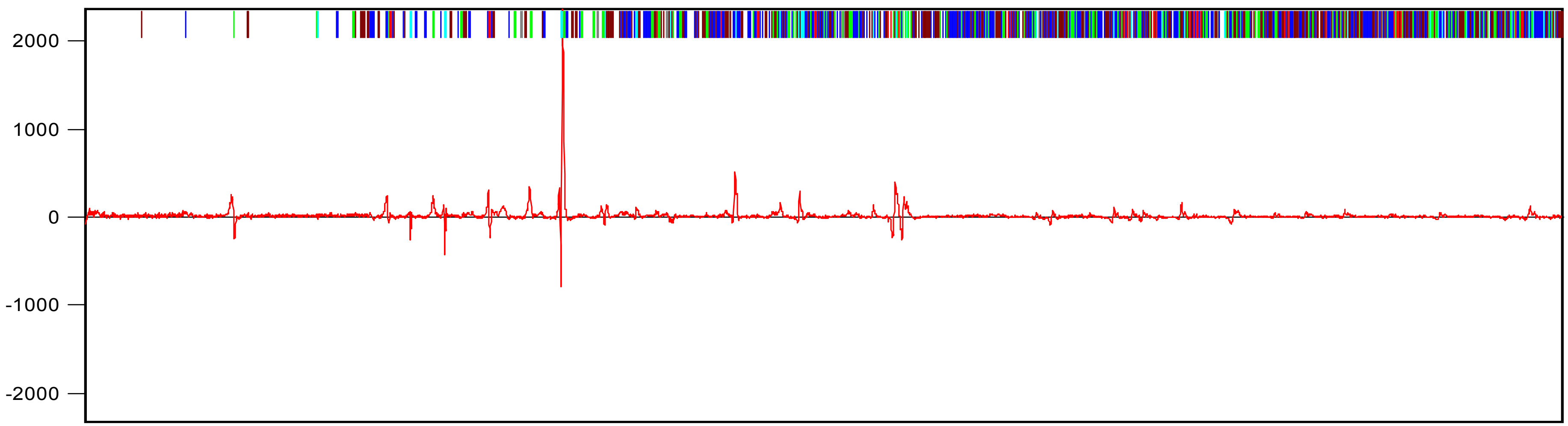

1500
1000
500
0
-500
-1000
-1500


Counts
DGR1-156.63
Quartz 1.2 %
Dolomite Ferrian 98.8 %
15000
10000
5000
0
10
20
30
40
50
60
70
80
Position [°2Theta] (Copper (Cu))

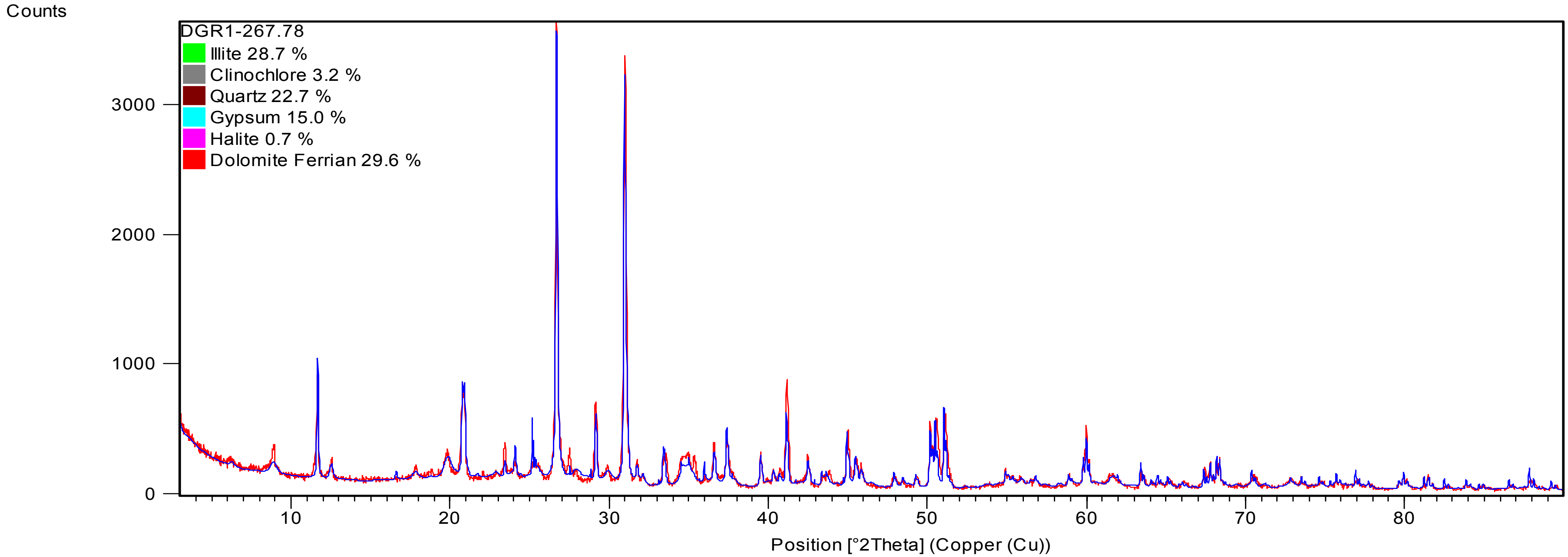

800
600
400
200
0
-200
-400
-600
-800

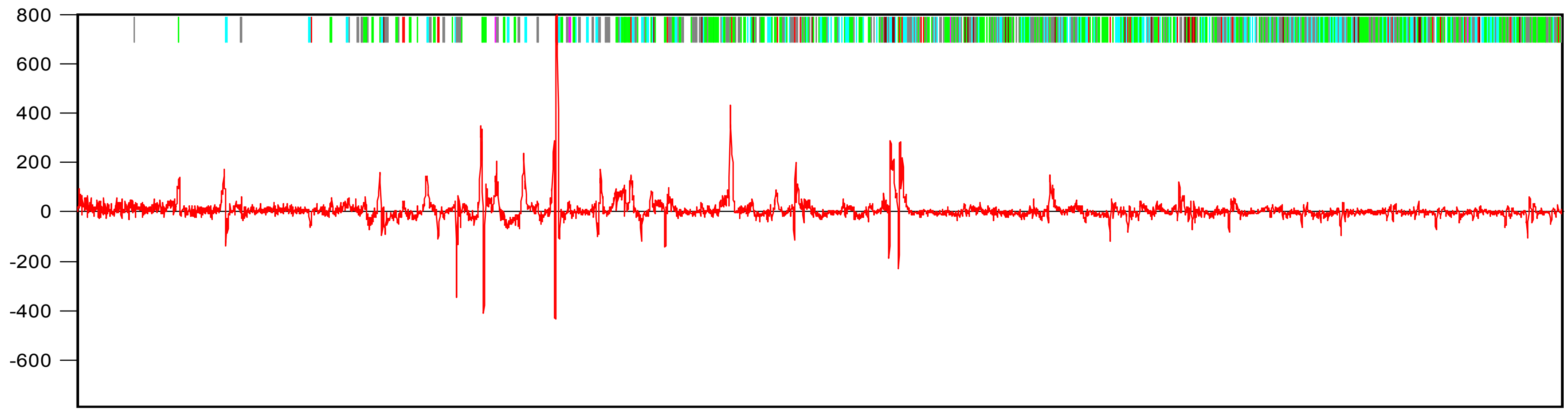


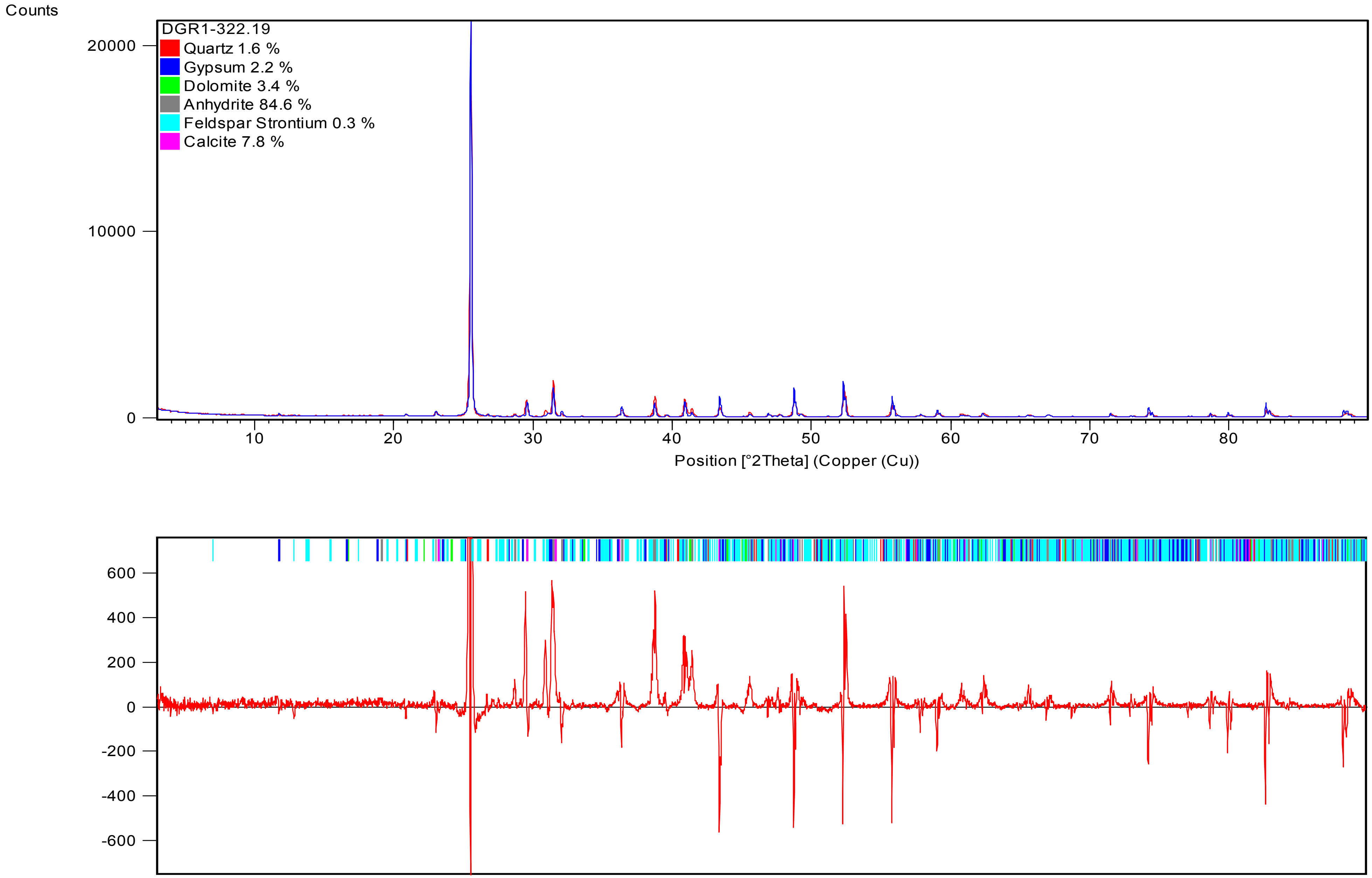
Counts
DGR1-231.49
Quartz 5.1 %
Illite 4.3 %
Gypsum 13.5 %
Dolomite 76.1 %
Pyrite 0.1 %
Clinochlore 0.9 %
8000
6000
4000
2000
0
10
20
30
40
50
60
70
80
Position [°2Theta] (Copper (Cu))

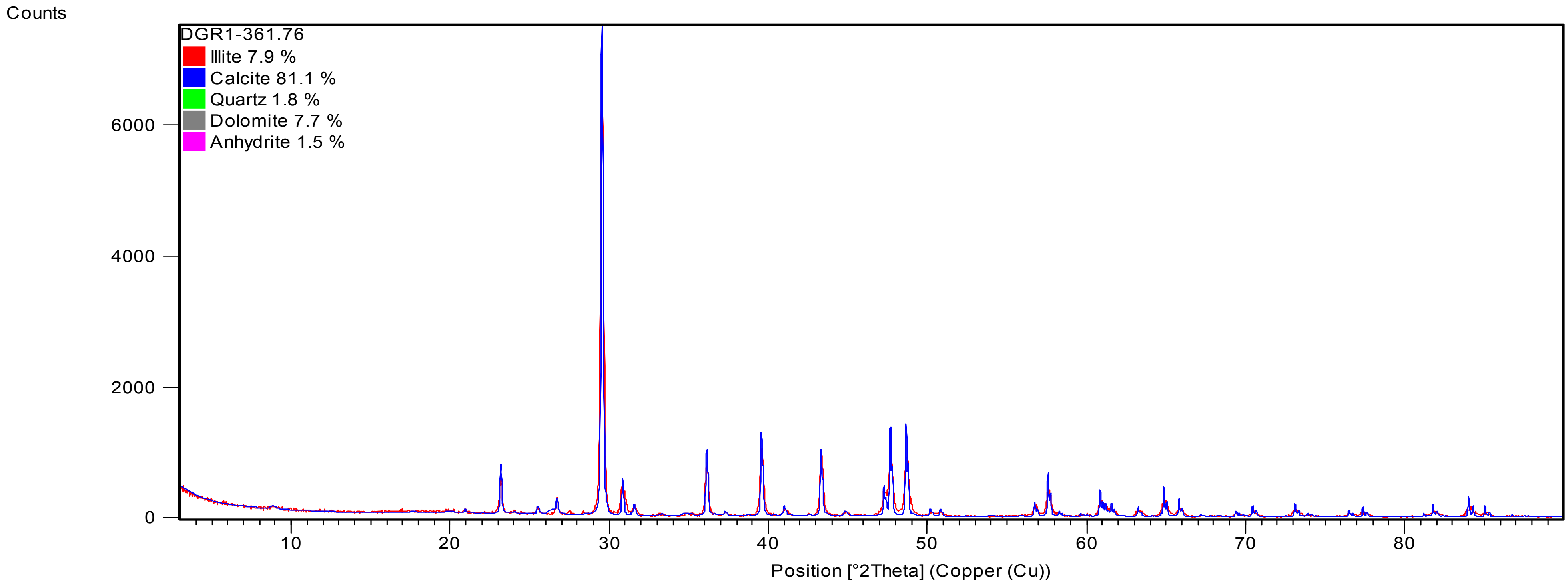


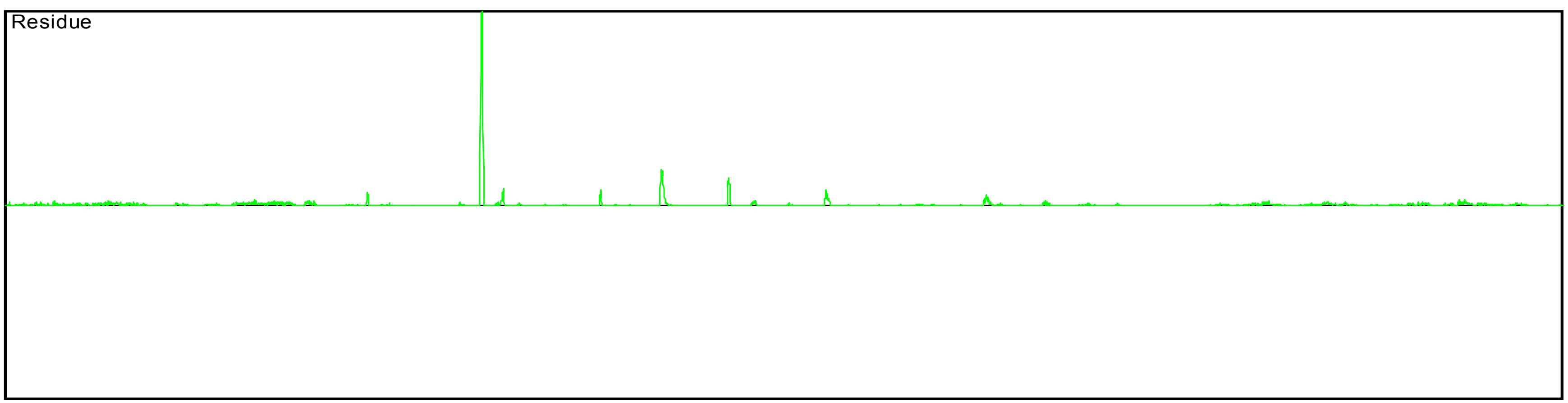
2000
1000
0
-1000
-2000

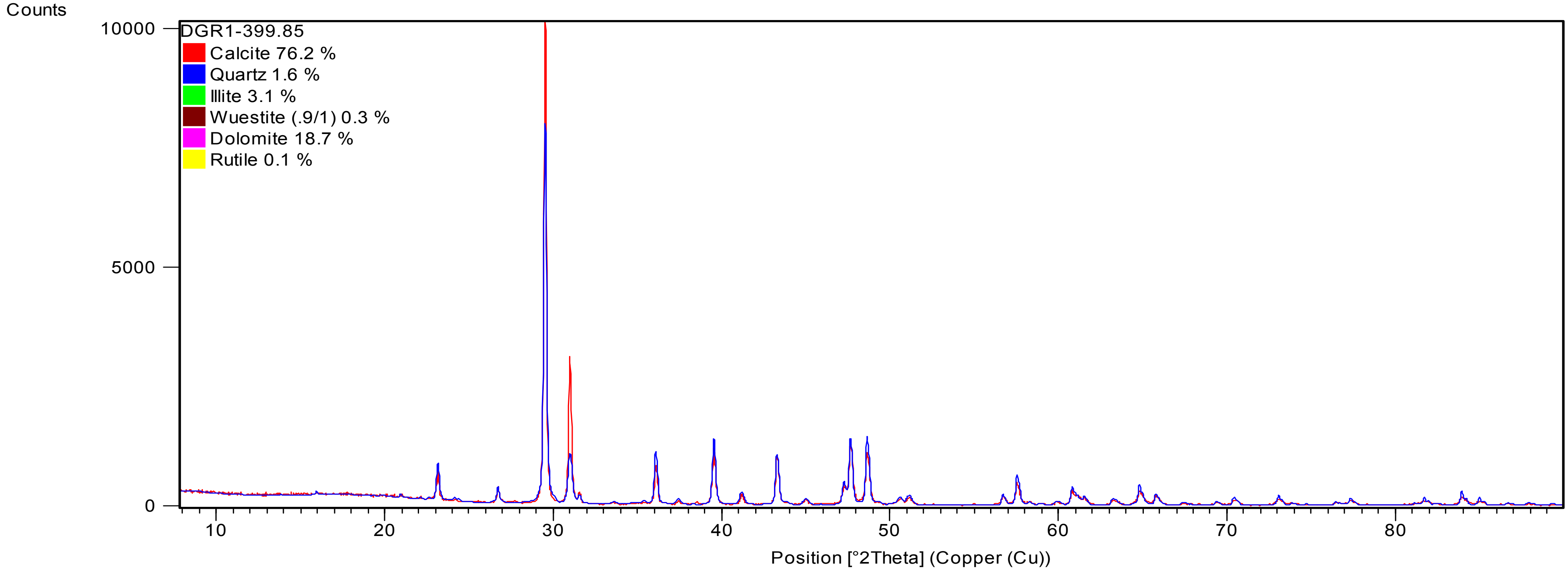

Counts
DGR1-267.78
Illite 28.7 %
Clinochlore 3.2 %
Quartz 22.7 %
Gypsum 15.0 %
Halite 0.7 %
Dolomite Ferrian 29.6 %
3000
2000
1000
0
10
20
30
40
50
60
70
80
Position [°2Theta] (Copper (Cu))

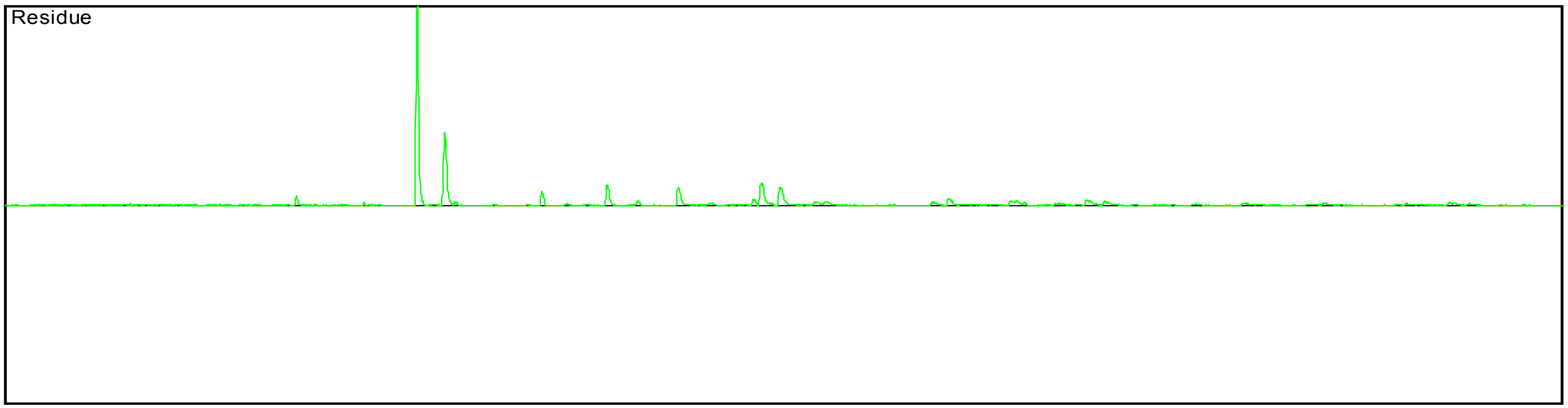

800
600
400
200
0
-200
-400
-600

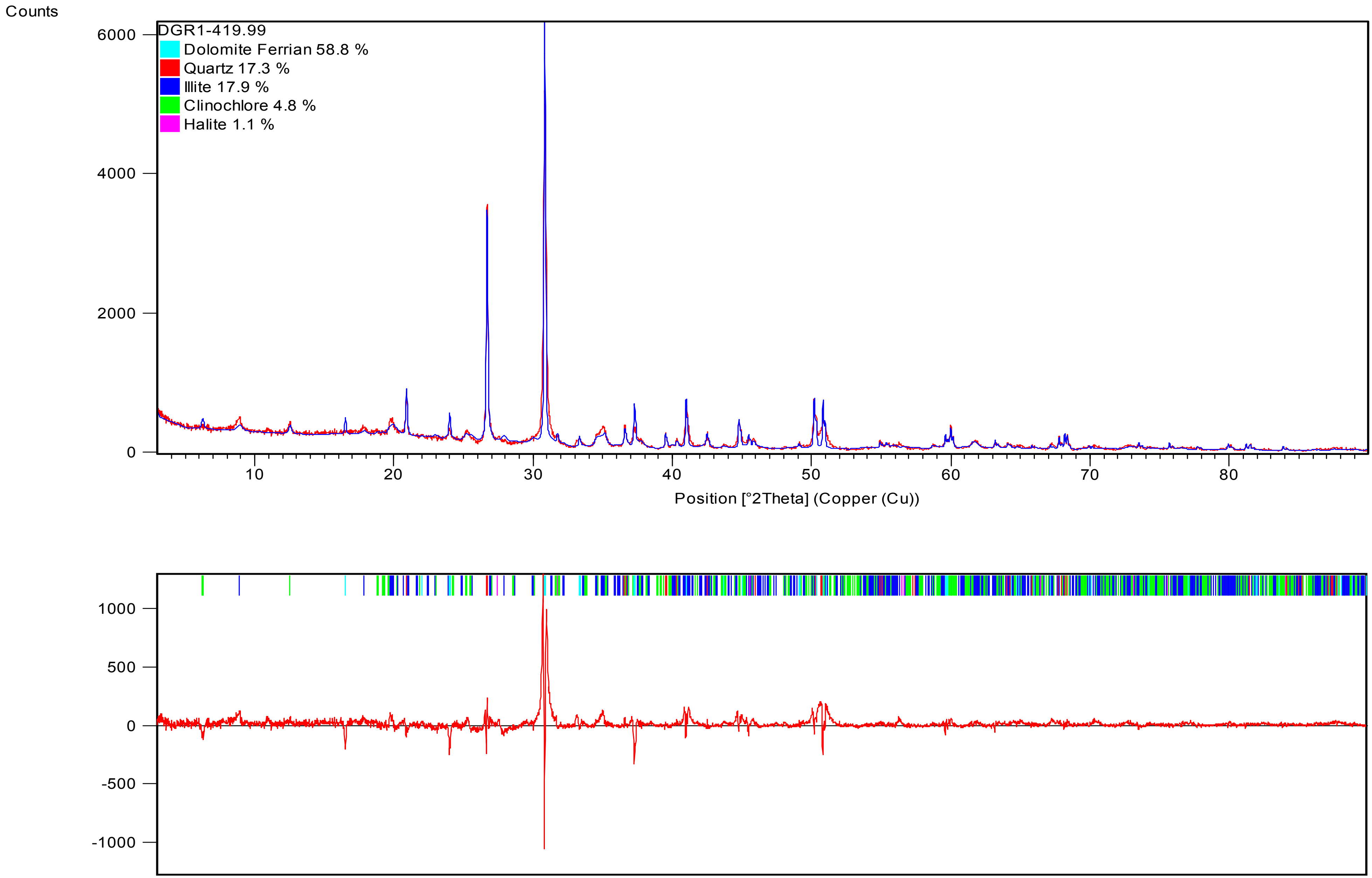

Counts
DGR1-322.19
Quartz 1.6 %
Gypsum 2.2 %
Dolomite 3.4 %
Anhydrite 84.6 %
Feldspar Strontium 0.3 %
Calcite 7.8 %
20000
10000
0
10
20
30
40
50
60
70
80
Position [°2Theta] (Copper (Cu))
600
400
200
0
-200
-400
-600

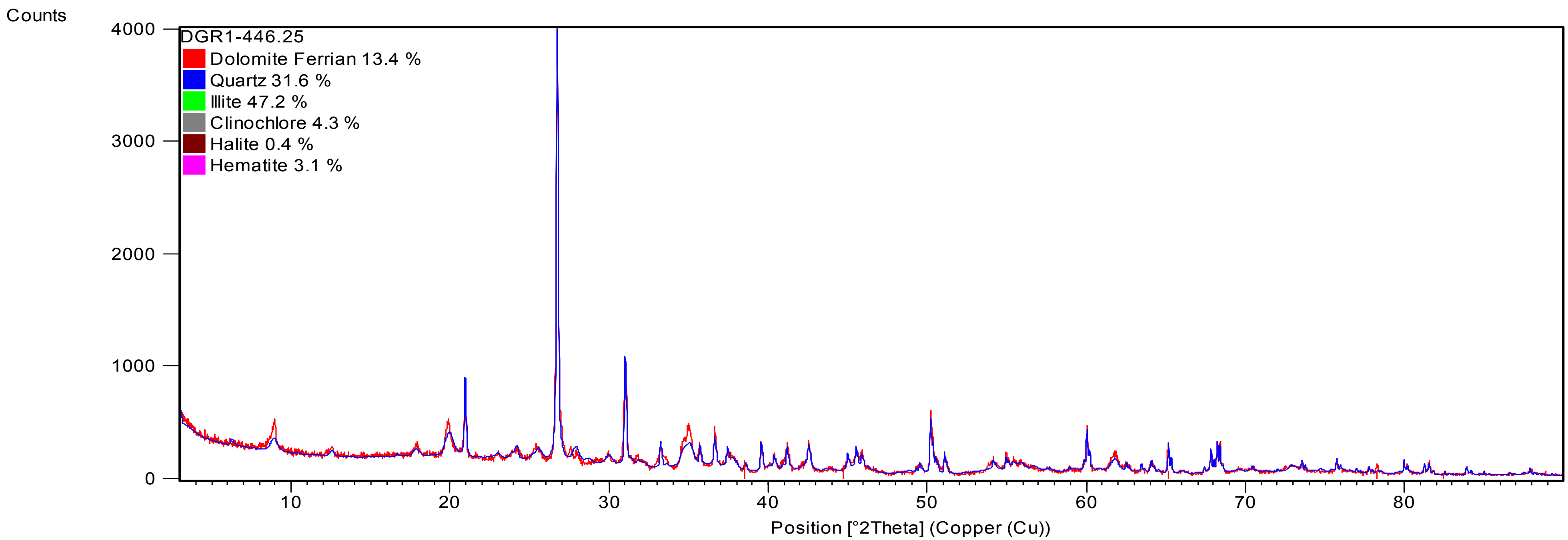

Counts
DGR1-361.76
Illite 7.9 %
Calcite 81.1 %
Quartz 1.8 %
Dolomite 7.7 %
Anhydrite 1.5 %
6000
4000
2000
0
10
20
30
40
50
60
70
80
Position [°2Theta] (Copper (Cu))

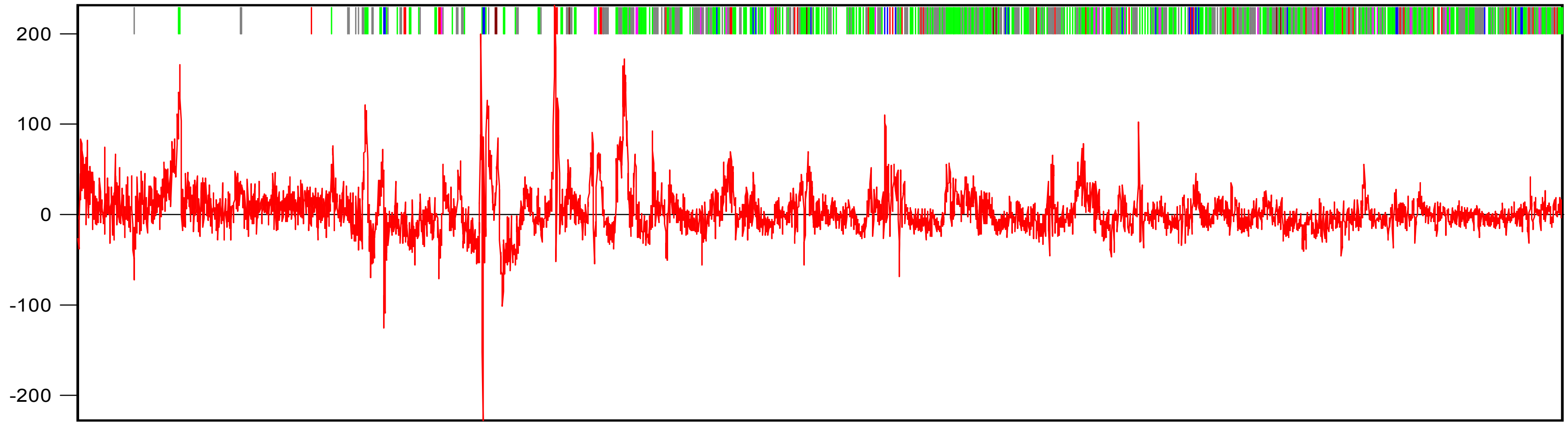

Residue

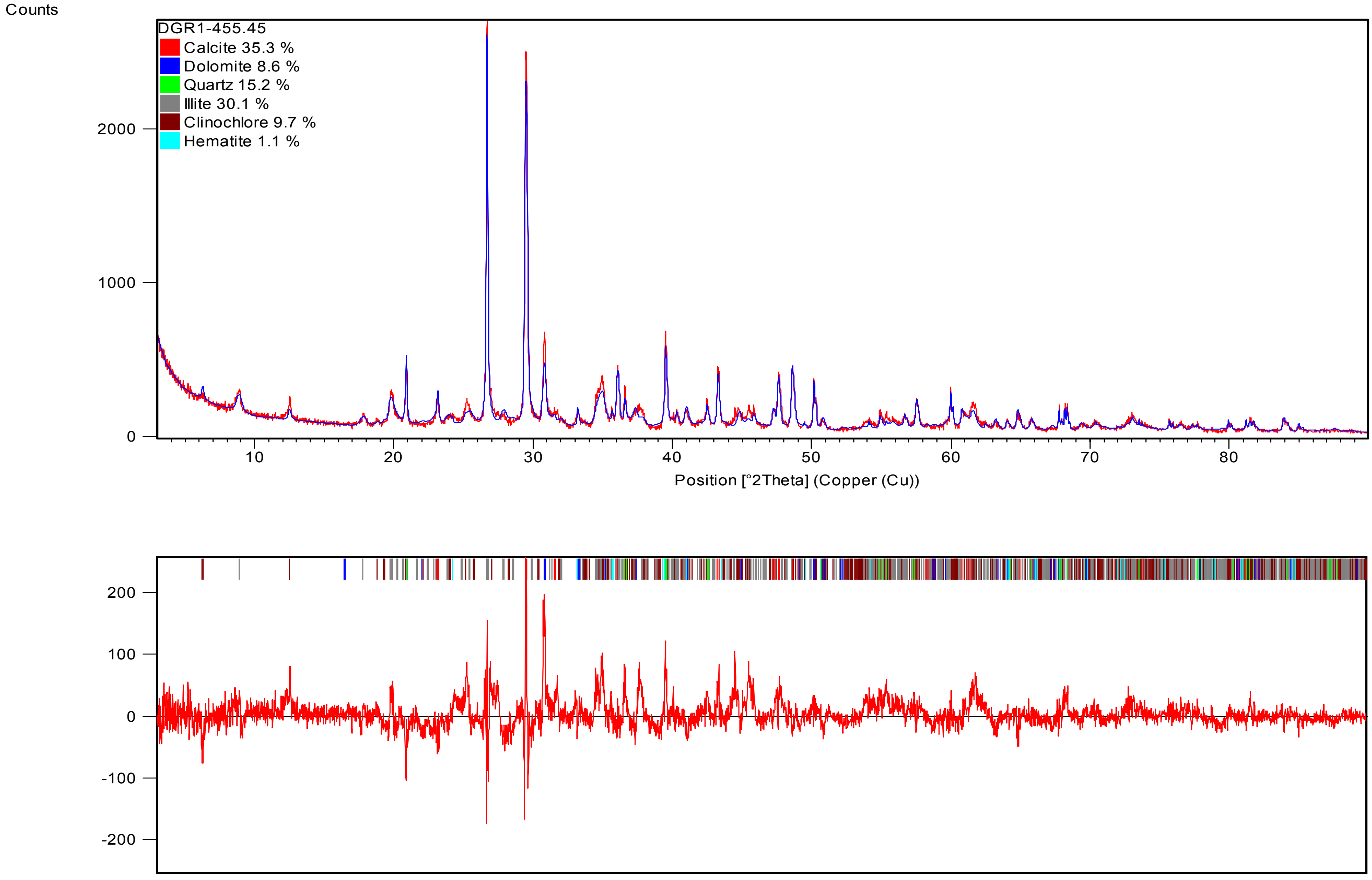

Counts
10000
5000
0
DGR1-399.85
Calcite 76.2 %
Quartz 1.6 %
Illite 3.1 %
Wuestite (.9/1) 0.3 %
Dolomite 18.7 %
Rutile 0.1 %
10
20
30
40
50
60
70
80
Position [°2Theta] (Copper (Cu))

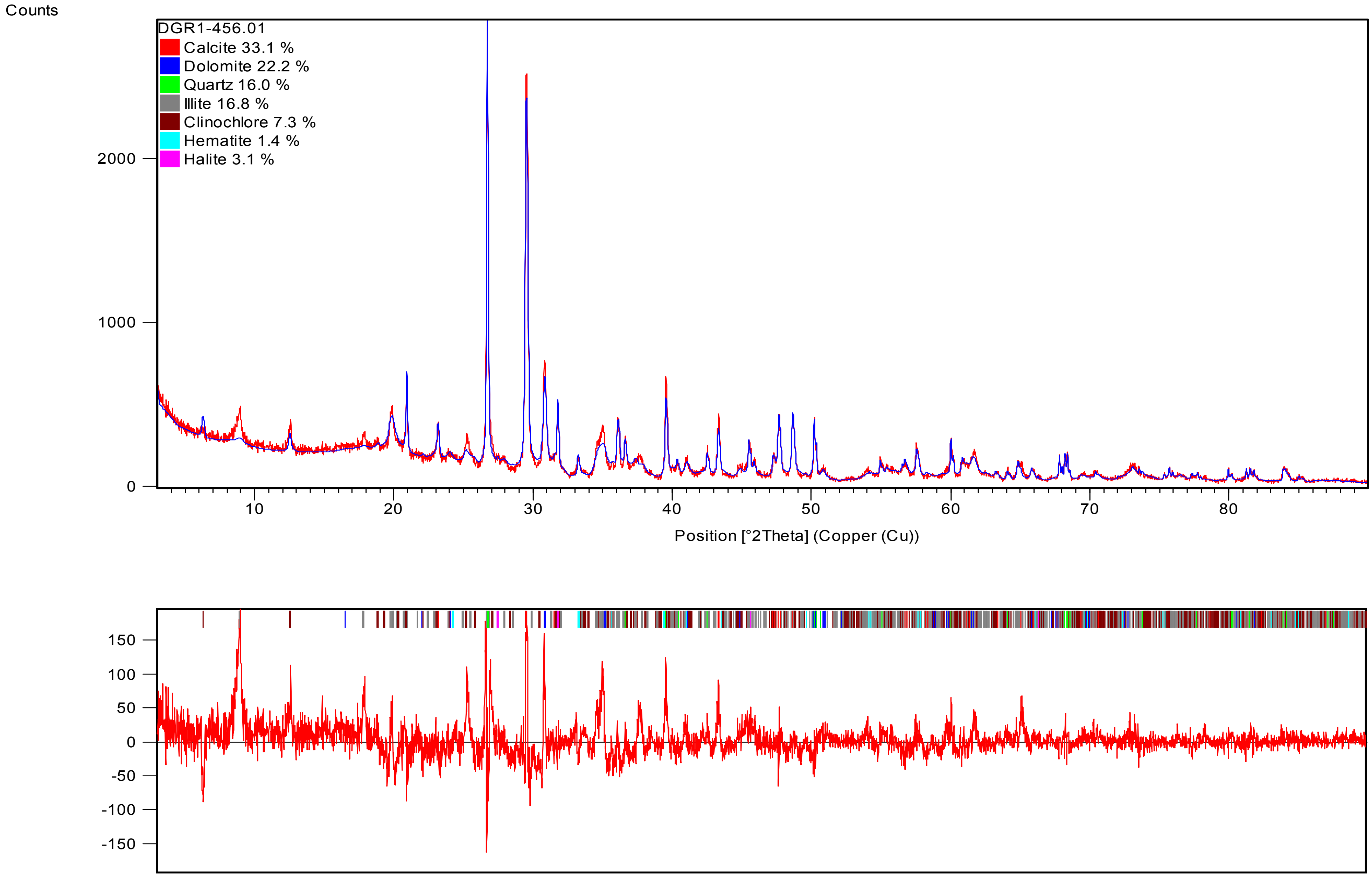

Residue

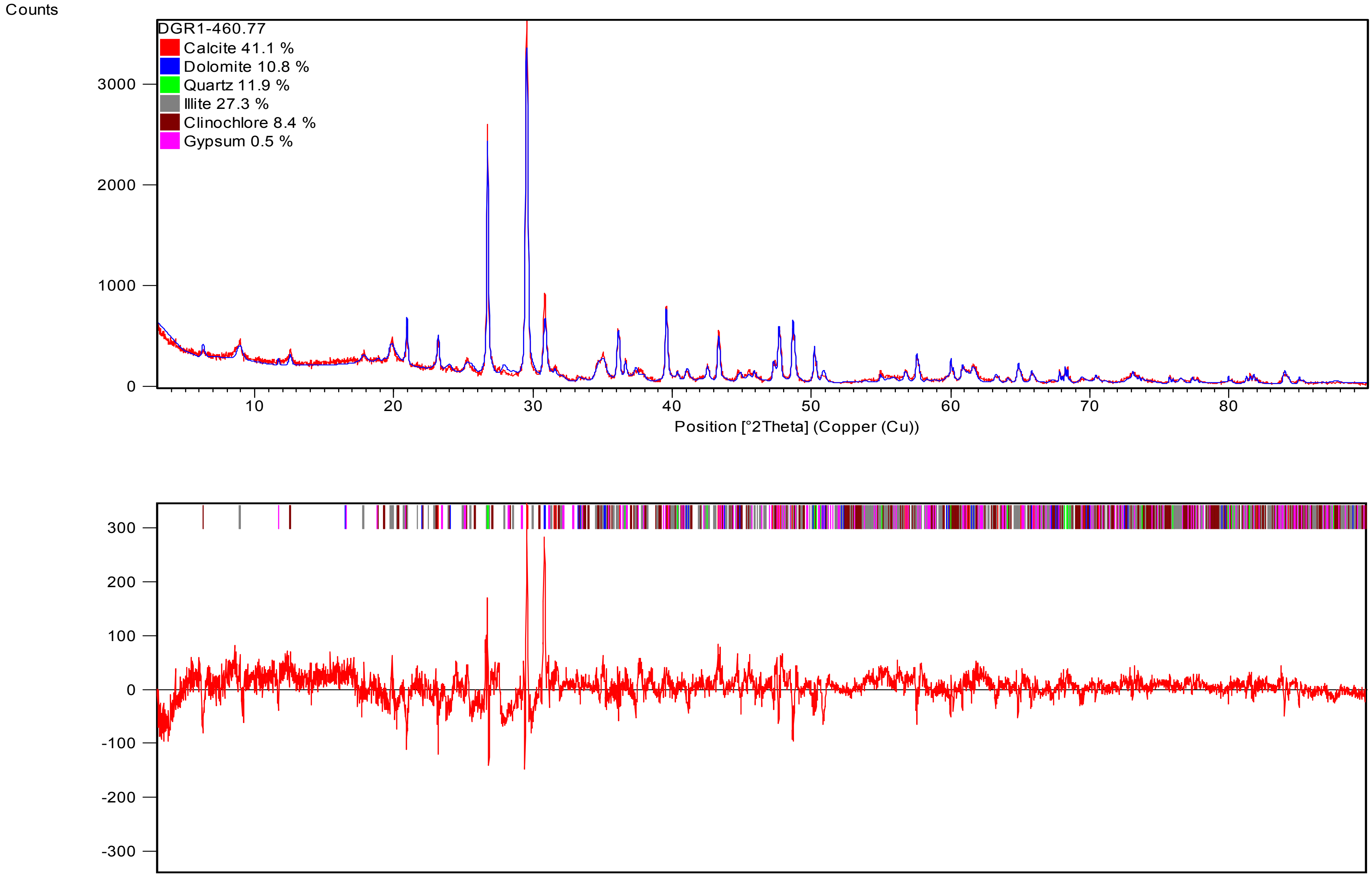

Counts
DGR1-419.99
Dolomite Ferrian 58.8 %
Quartz 17.3 %
Illite 17.9 %
Clinochlore 4.8 %
Halite 1.1 %
6000
4000
2000
0
10
20
30
40
50
60
70
80
Position [°2Theta] (Copper (Cu))
1000
500
0
-500
-1000

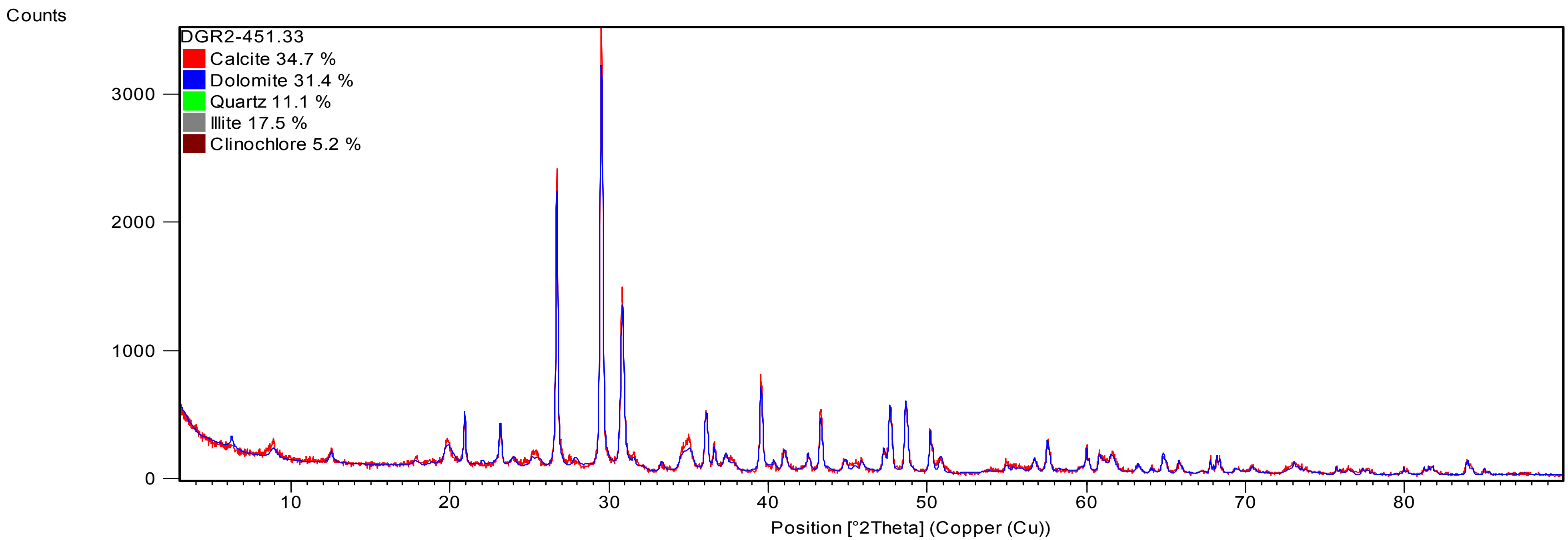

Counts
4000
3000
2000
1000
0
DGR1-446.25
Dolomite Ferrian 13.4 %
Quartz 31.6 %
Illite 47.2 %
Clinochlore 4.3 %
Halite 0.4 %
Hematite 3.1 %
10
20
30
40
50
60
70
80
Position [°2Theta] (Copper (Cu))

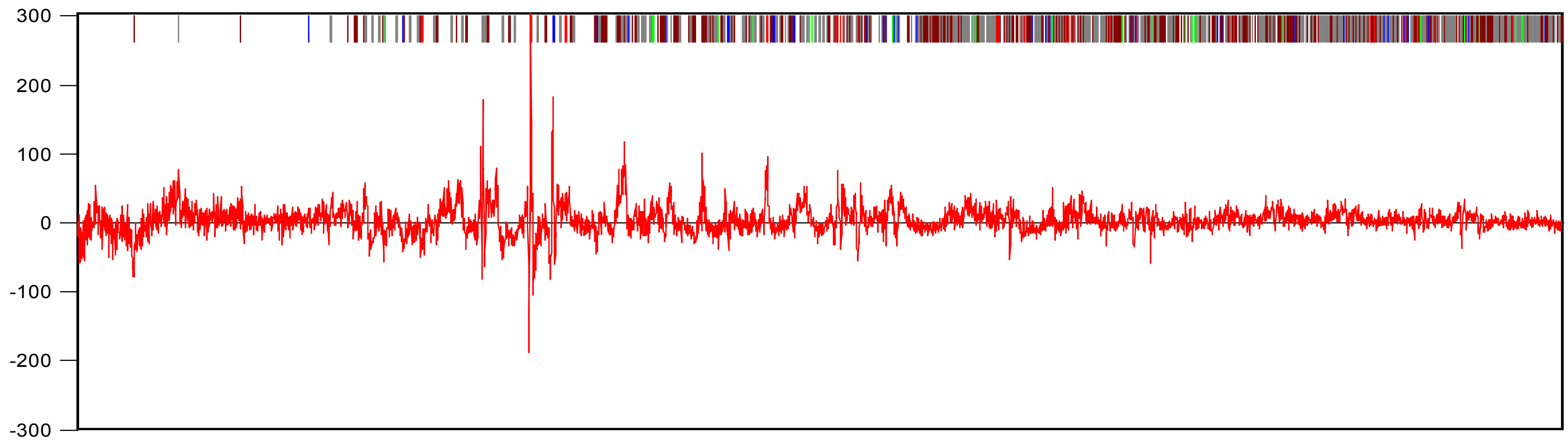

200
100
0
-100
-200

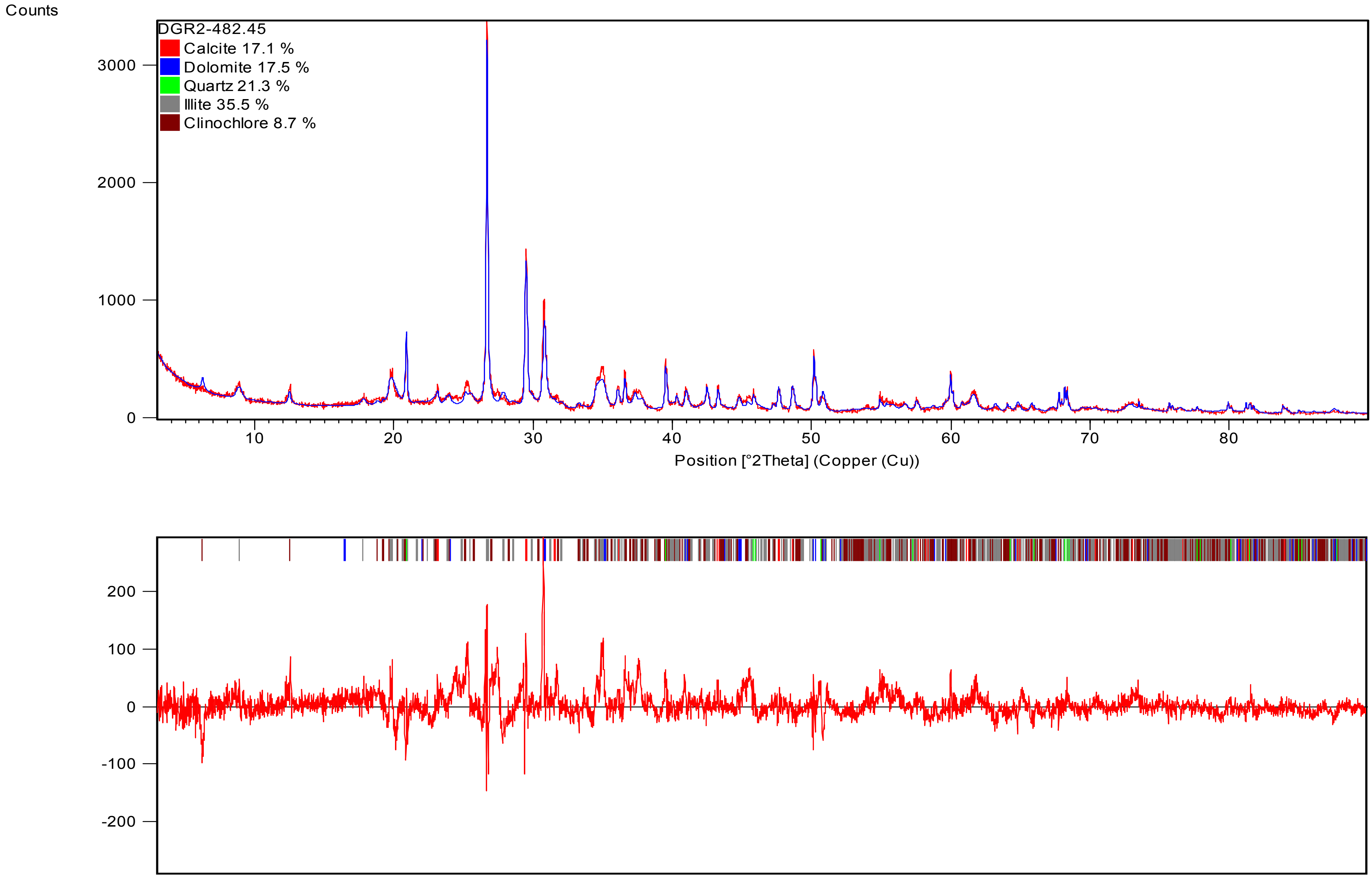

Counts
DGR1-455.45
Calcite 35.3 %
Dolomite 8.6 %
Quartz 15.2 %
Illite 30.1 %
Clinochlore 9.7 %
Hematite 1.1 %
2000
1000
0
10
20
30
40
50
60
70
80
Position [°2Theta] (Copper (Cu))
200
100
0
-100
-200

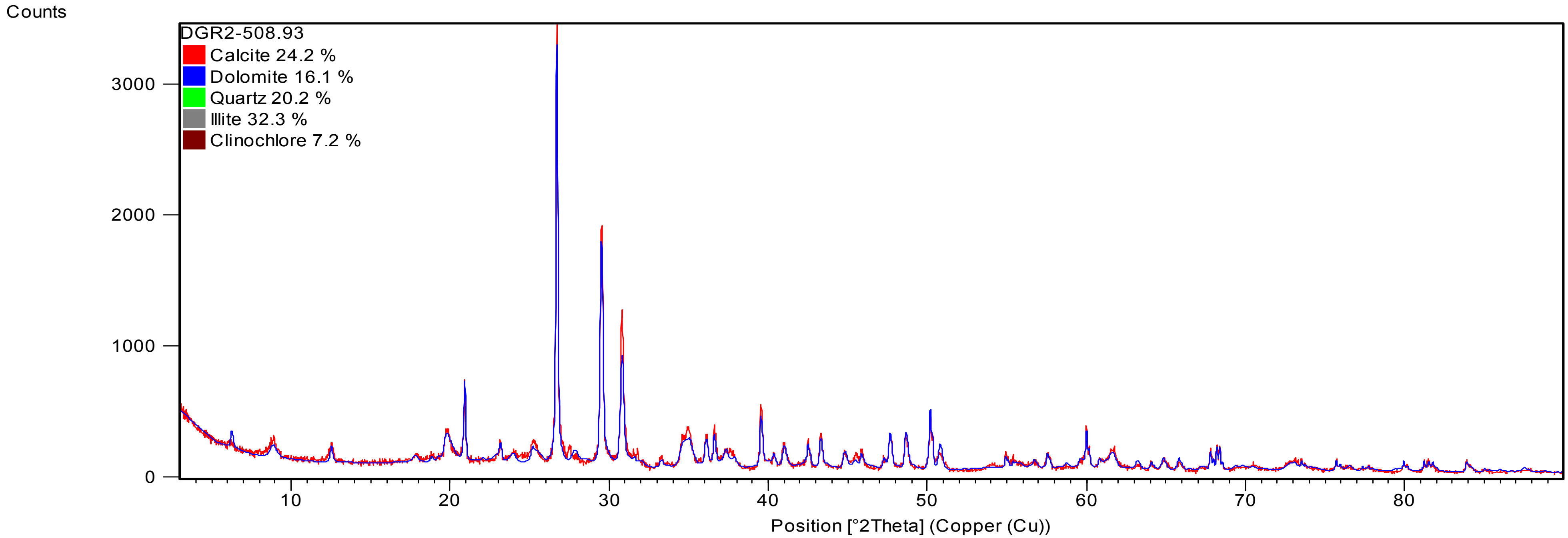

Counts
DGR1-456.01
Calcite 33.1 %
Dolomite 22.2 %
Quartz 16.0 %
Illite 16.8 %
Clinochlore 7.3 %
Hematite 1.4 %
Halite 3.1 %
2000
1000
0
10
20
30
40
50
60
70
80
Position [°2Theta] (Copper (Cu))
150
100
50
0
-50
-100
-150

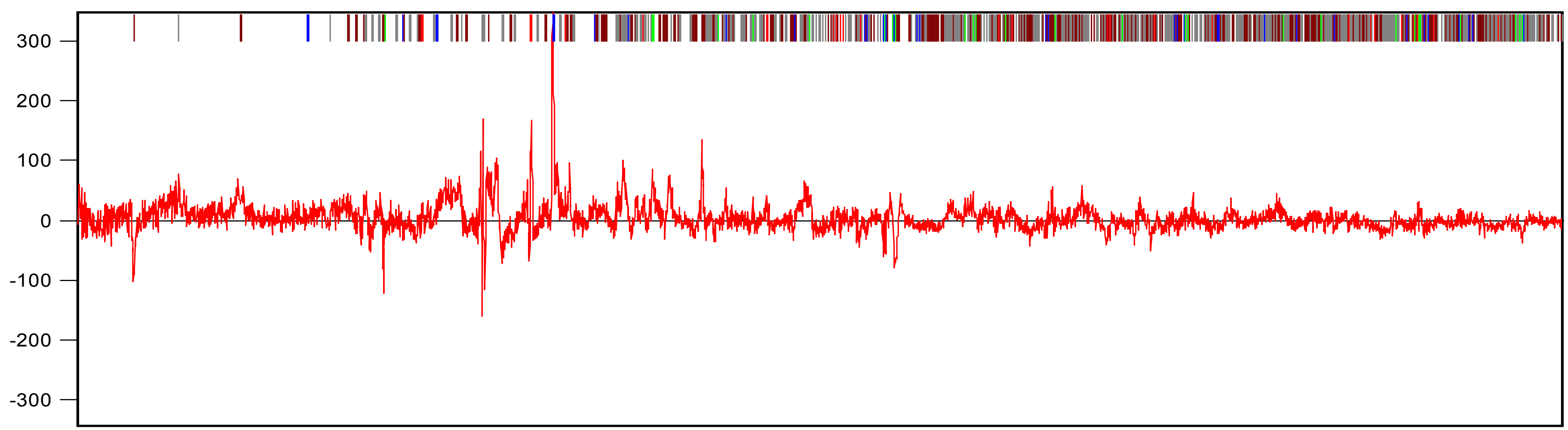

Counts
DGR1-460.77
Calcite 41.1 %
Dolomite 10.8 %
Quartz 11.9 %
Illite 27.3 %
Clinochlore 8.4 %
Gypsum 0.5 %
3000
2000
1000
0
10
20
30
40
50
60
70
80
Position [°2Theta] (Copper (Cu))
300
200
100
0
-100
-200
-300

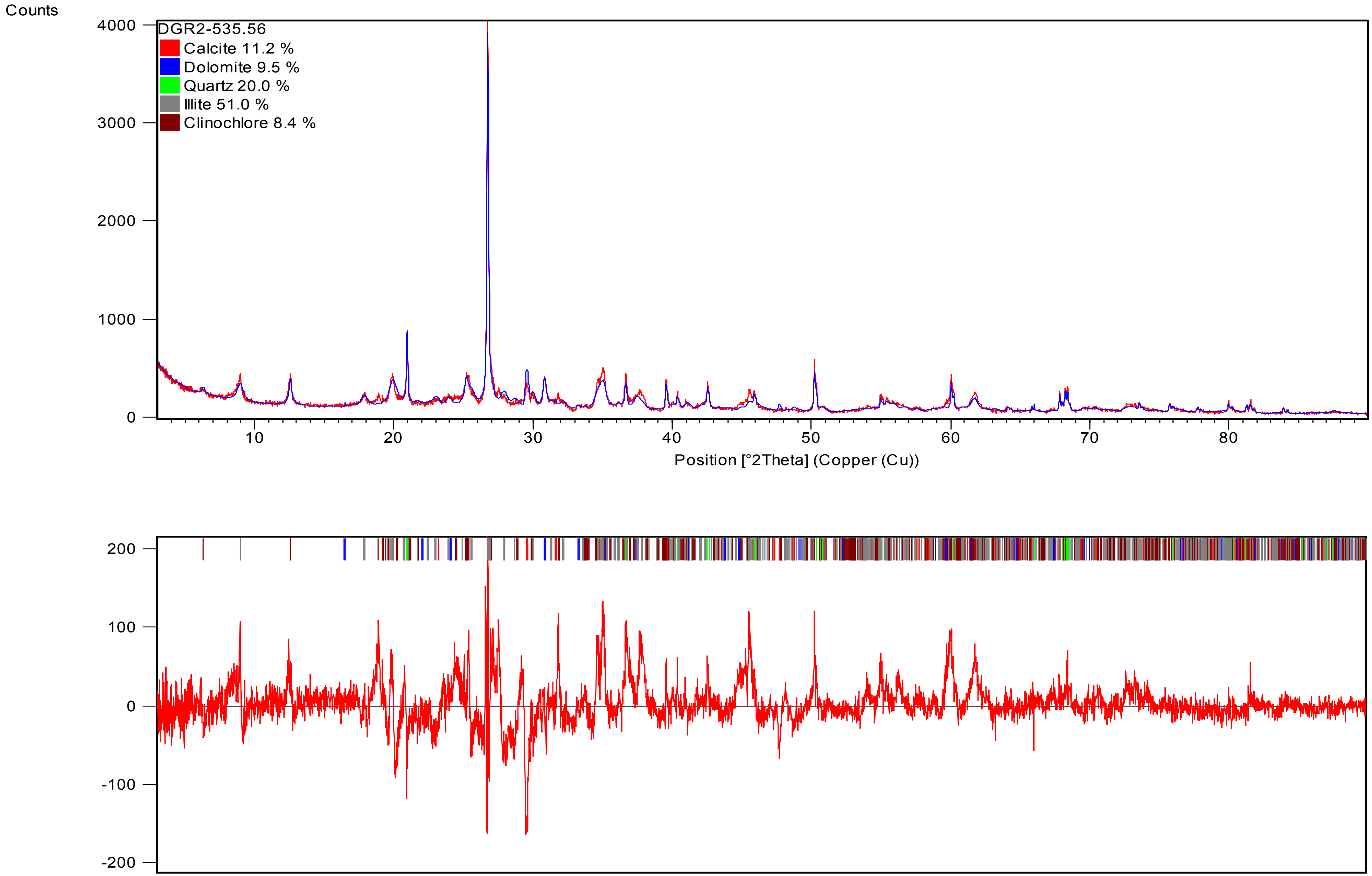

Counts
DGR2-451.33
Calcite 34.7 %
Dolomite 31.4 %
Quartz 11.1 %
Illite 17.5 %
Clinochlore 5.2 %
3000
2000
1000
0
10
20
30
40
50
60
70
80
Position [°2Theta] (Copper (Cu))

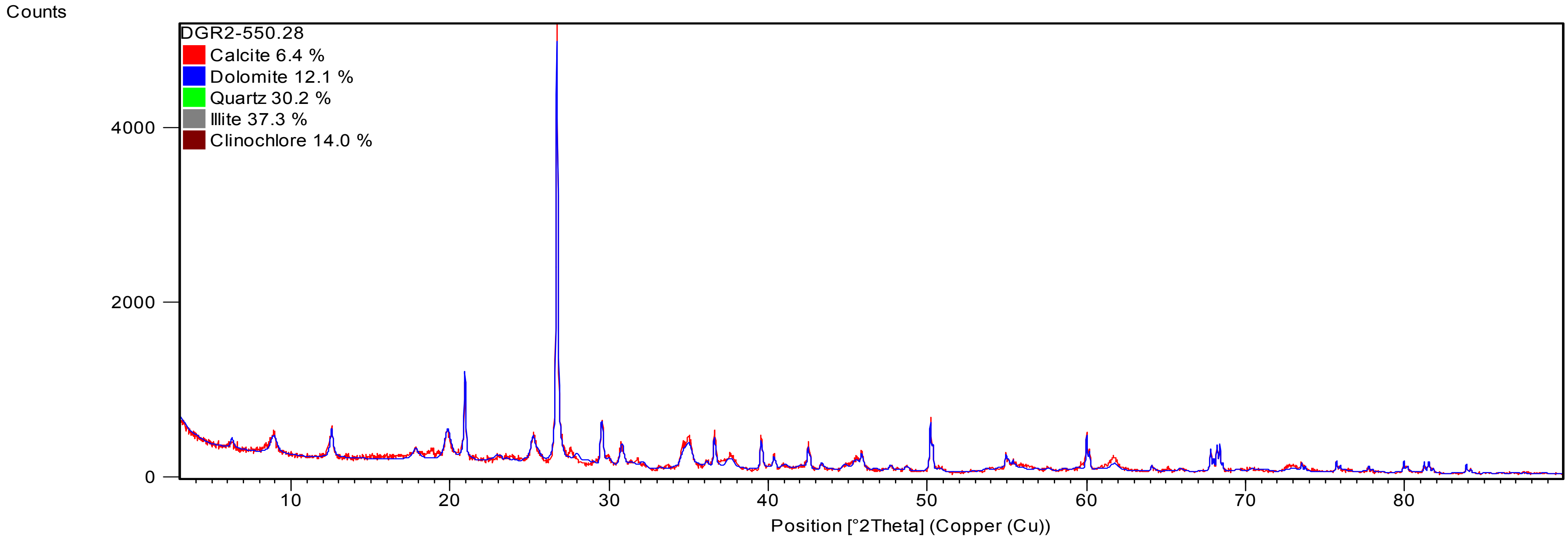

300
200
100
0
-100
-200
-300

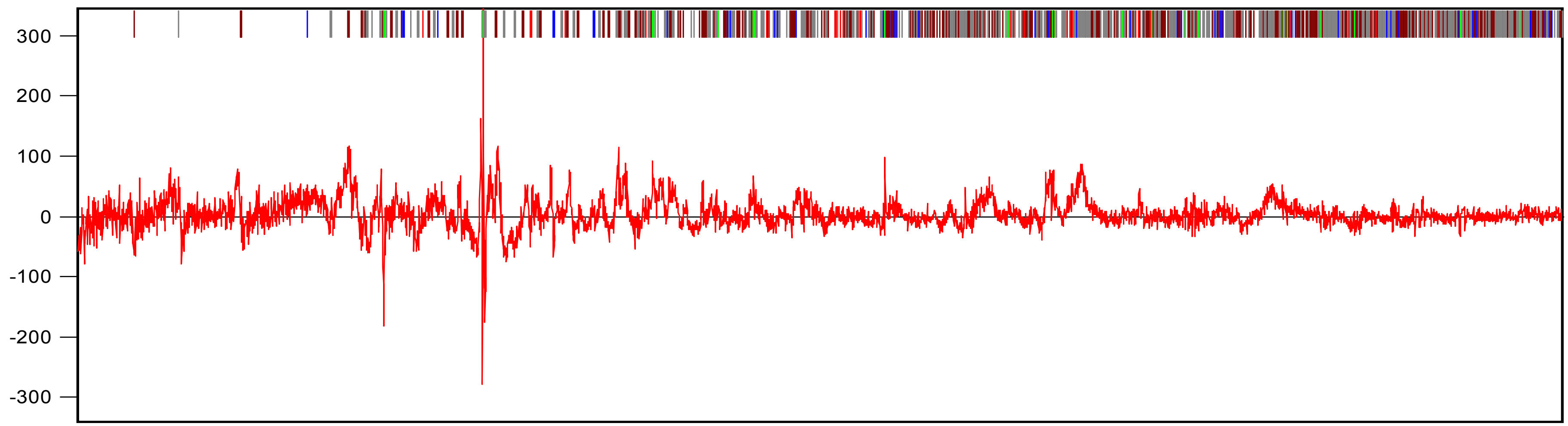

Counts
DGR2-482.45
Calcite 17.1 %
Dolomite 17.5 %
Quartz 21.3 %
Illite 35.5 %
Clinochlore 8.7 %
3000
2000
1000
0
10
20
30
40
50
60
70
80
Position [°2Theta] (Copper (Cu))
200
100
0
-100
-200

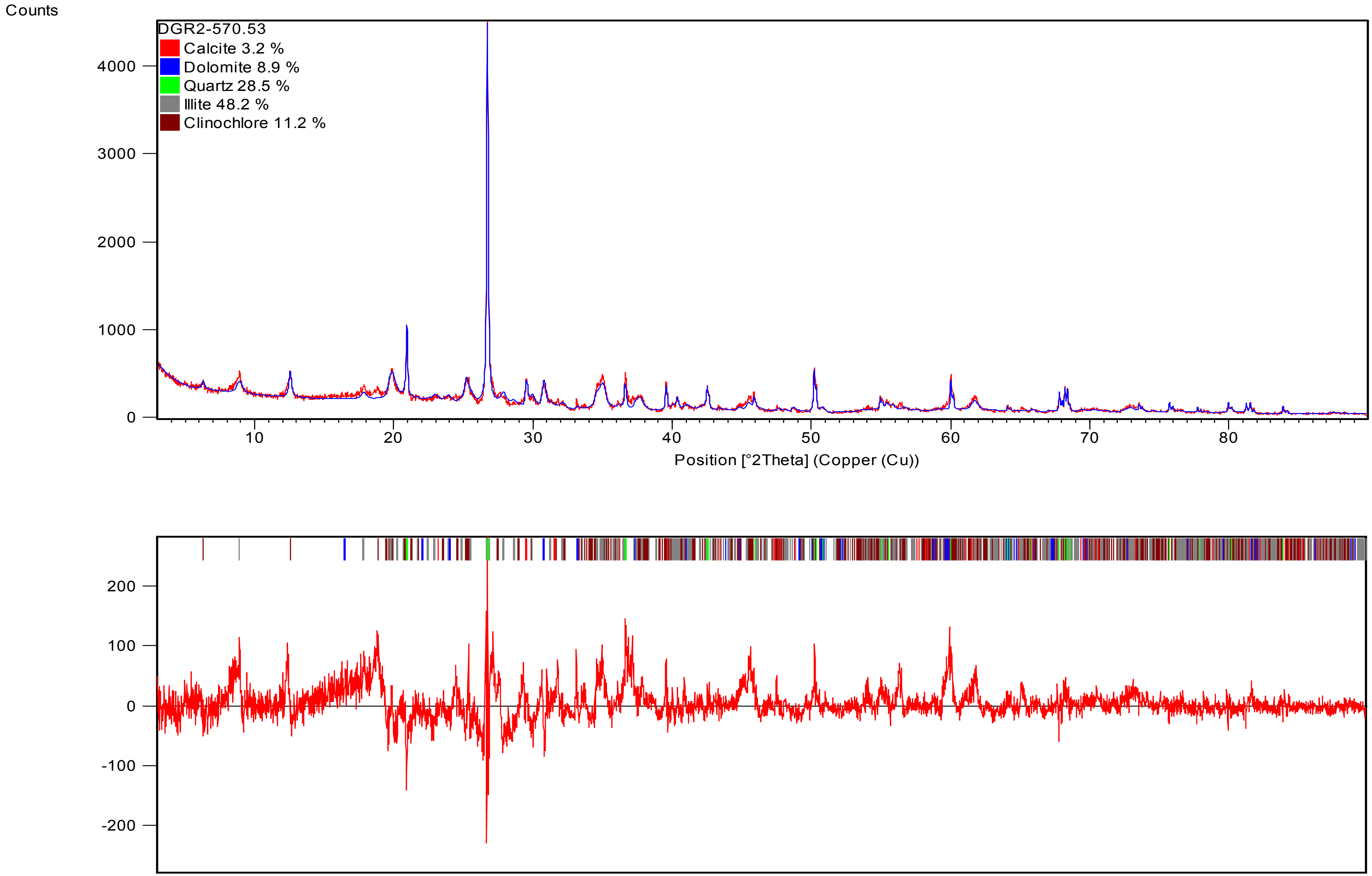

Counts
DGR2-508.93
Calcite 24.2 %
Dolomite 16.1 %
Quartz 20.2 %
Illite 32.3 %
Clinochlore 7.2 %
3000
2000
1000
0
10
20
30
40
50
60
70
80
Position [°2Theta] (Copper (Cu))

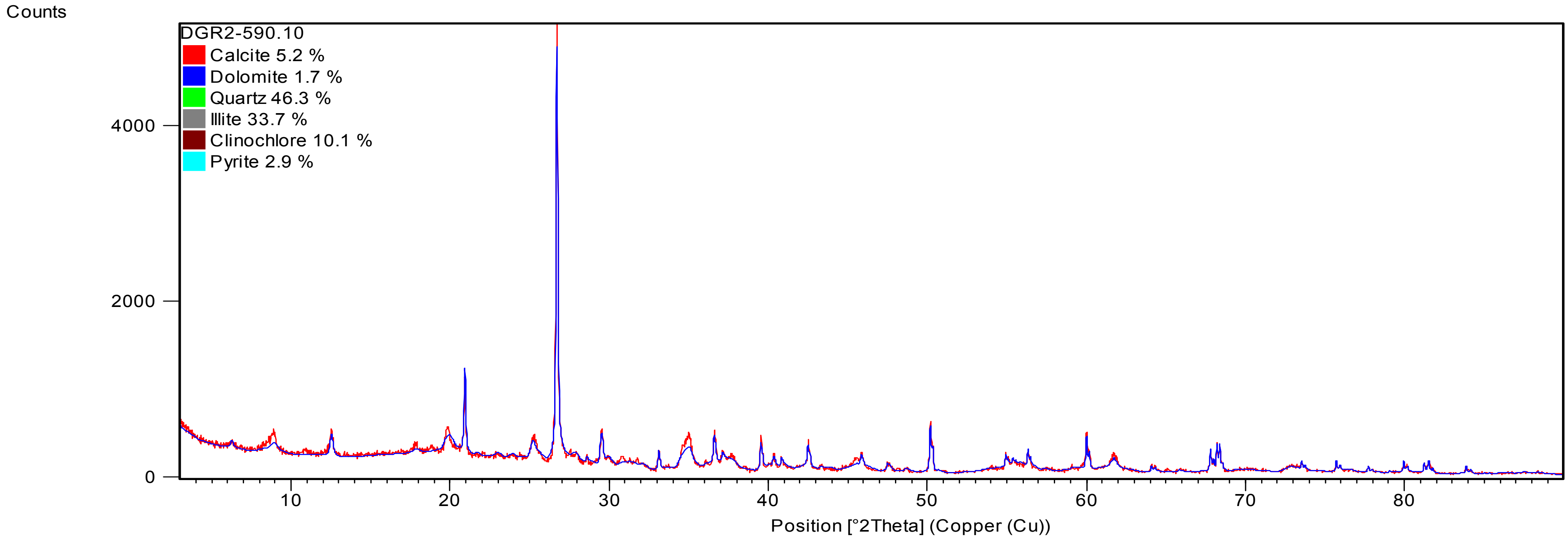

300
200
100
0
-100
-200
-300

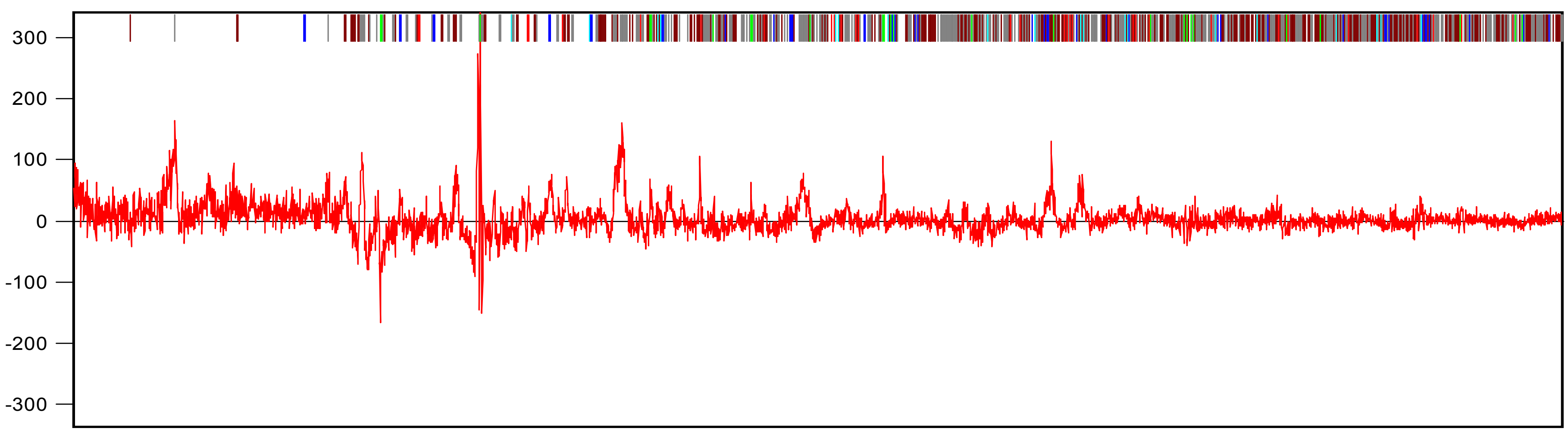

Counts
DGR2-535.56
Calcite 11.2 %
Dolomite 9.5 %
Quartz 20.0 %
Illite 51.0 %
Clinochlore 8.4 %
4000
3000
2000
1000
0
10
20
30
40
50
60
70
80
Position [°2Theta] (Copper (Cu))
200
100
0
-100
-200

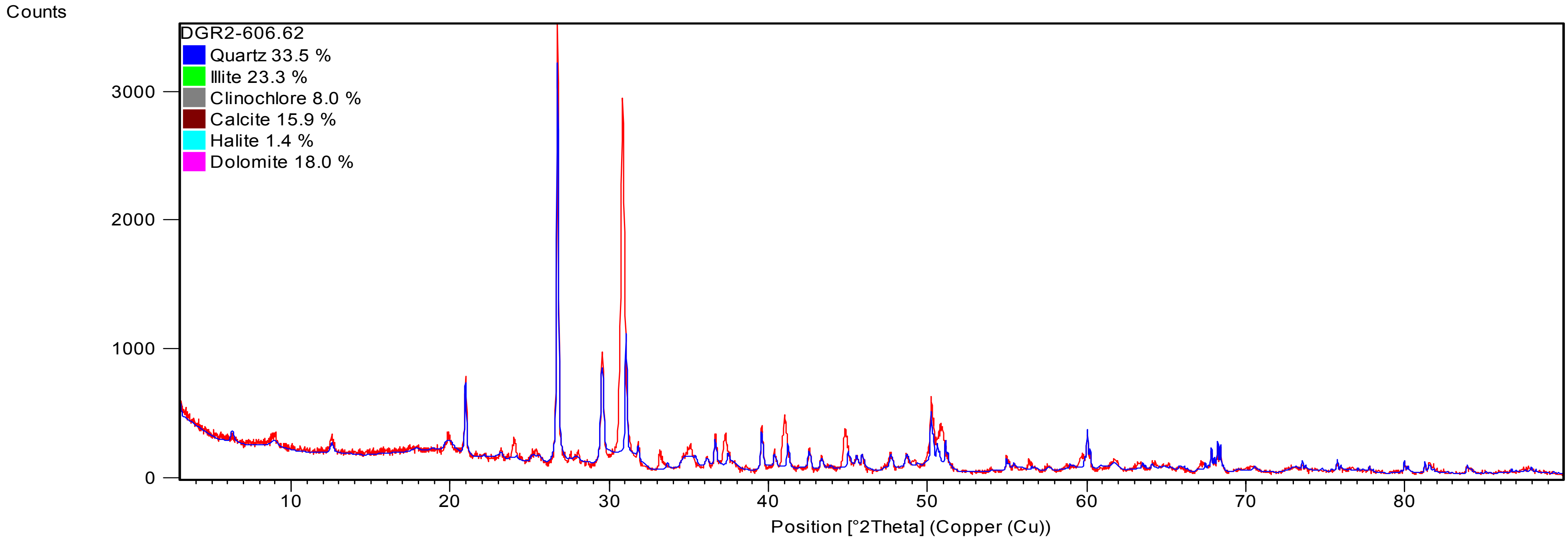

Counts
DGR2-550.28
Calcite 6.4 %
Dolomite 12.1 %
Quartz 30.2 %
Illite 37.3 %
Clinochlore 14.0 %
4000
2000
0
10
20
30
40
50
60
70
80
Position [°2Theta] (Copper (Cu))

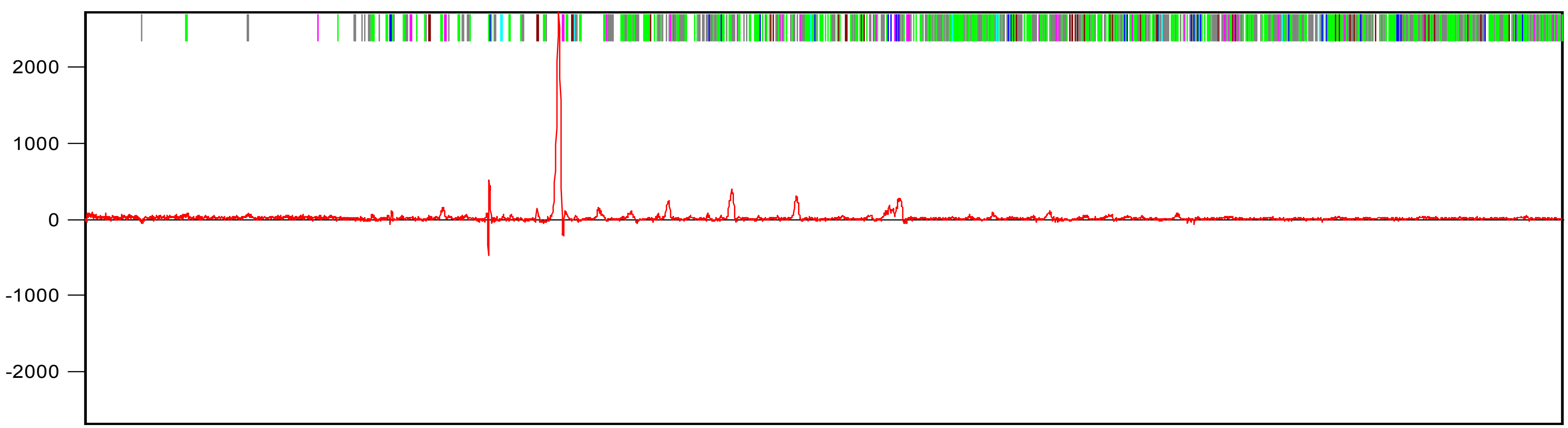

300
200
100
0
-100
-200
-300

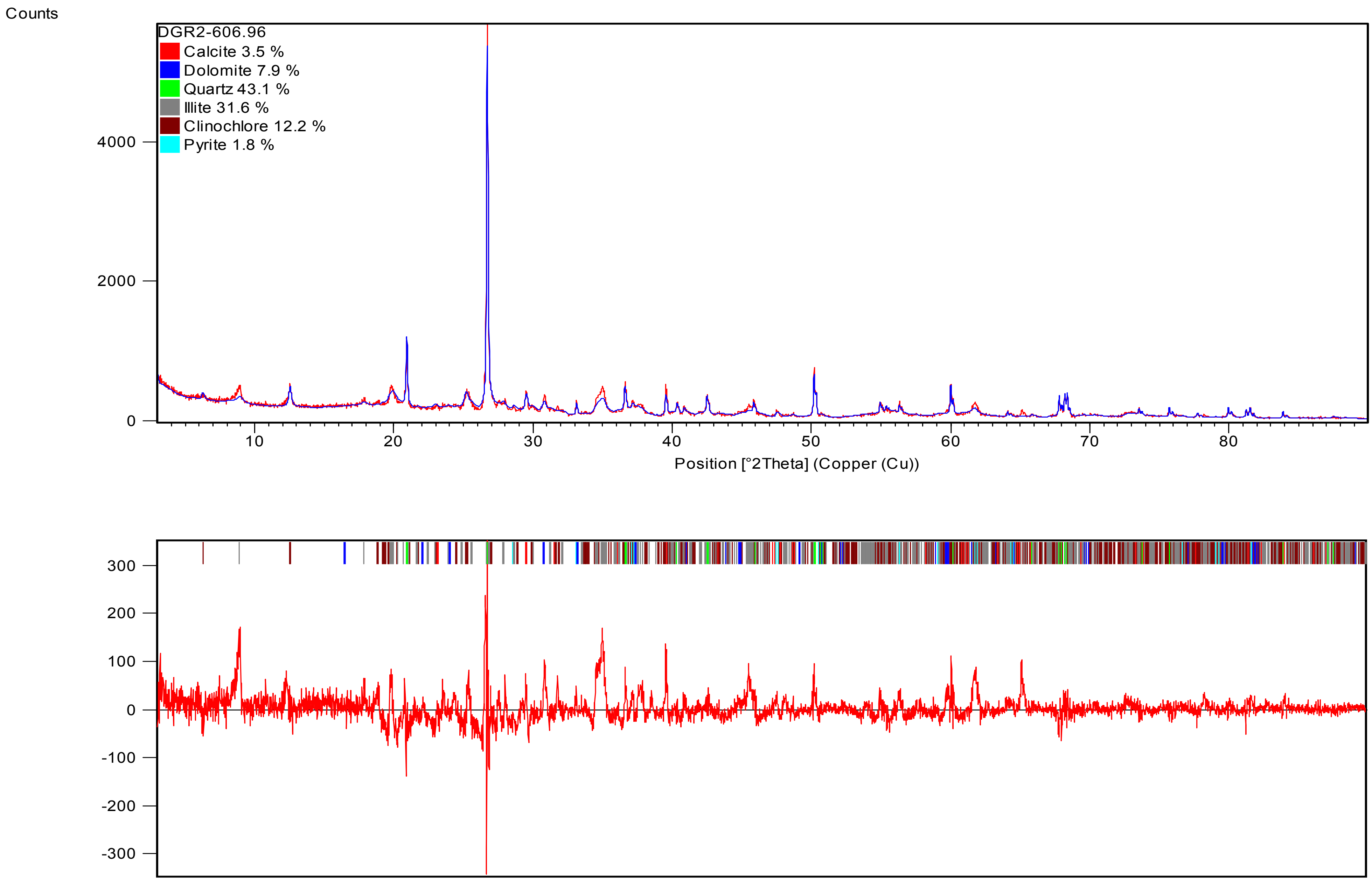

Counts
DGR2-570.53
Calcite 3.2 %
Dolomite 8.9 %
Quartz 28.5 %
Illite 48.2 %
Clinochlore 11.2 %
4000
3000
2000
1000
0
10
20
30
40
50
60
70
80
Position [°2Theta] (Copper (Cu))
200
100
0
-100
-200

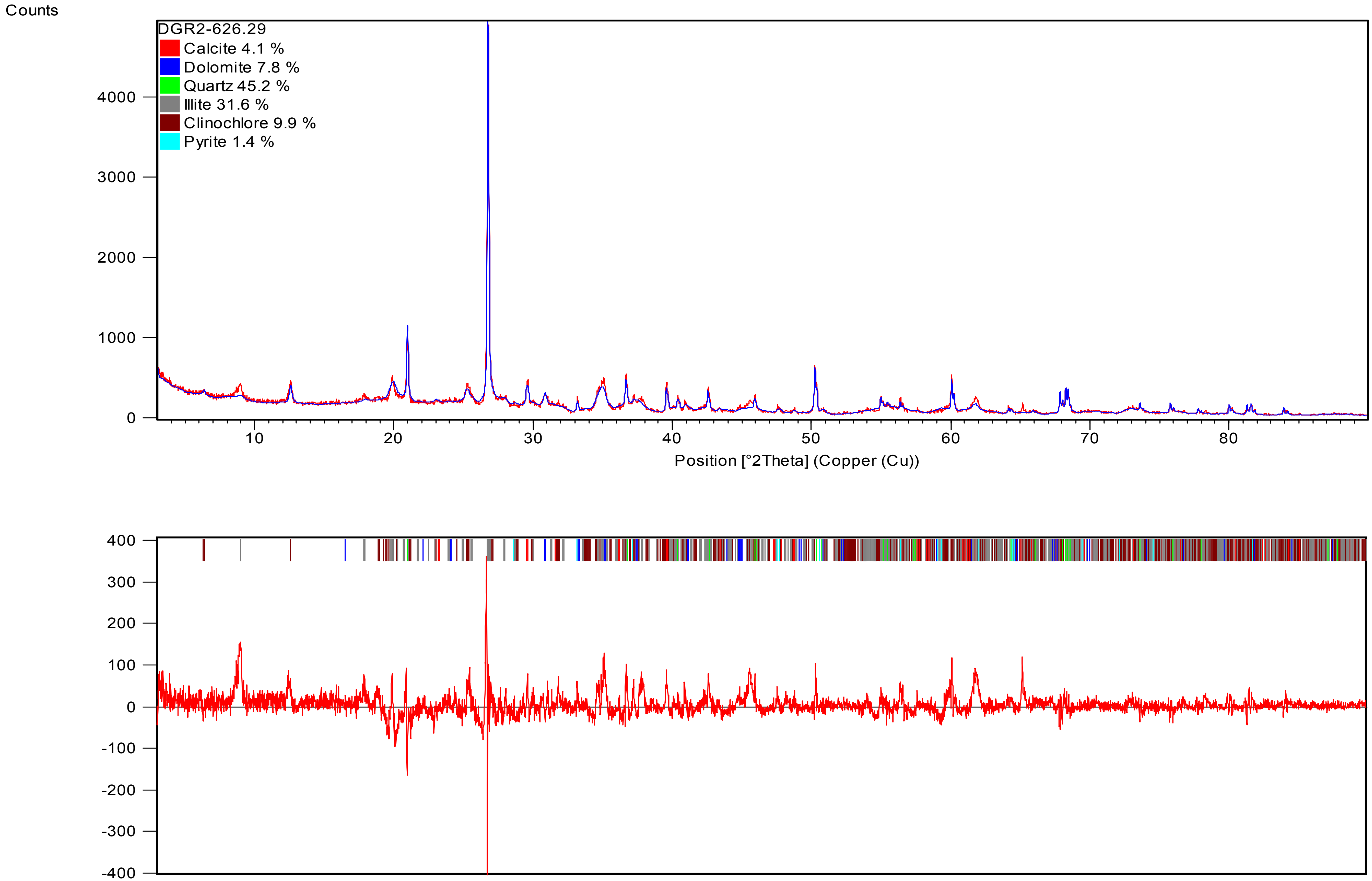

Counts
DGR2-590.10
Calcite 5.2 %
Dolomite 1.7 %
Quartz 46.3 %
Illite 33.7 %
Clinochlore 10.1 %
Pyrite 2.9 %
4000
2000
0
10
20
30
40
50
60
70
80
Position [°2Theta] (Copper (Cu))

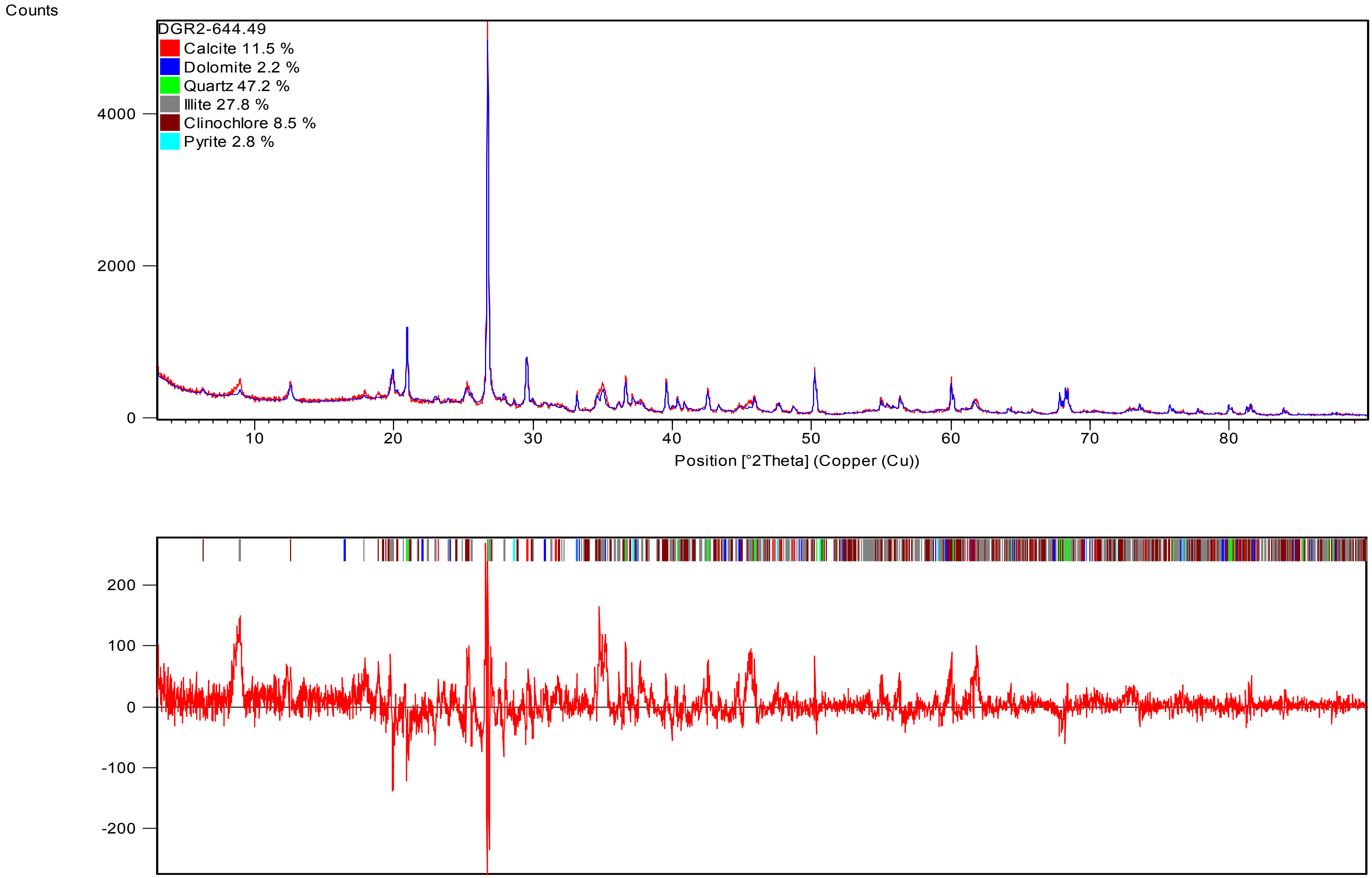

300
200
100
0
-100
-200
-300

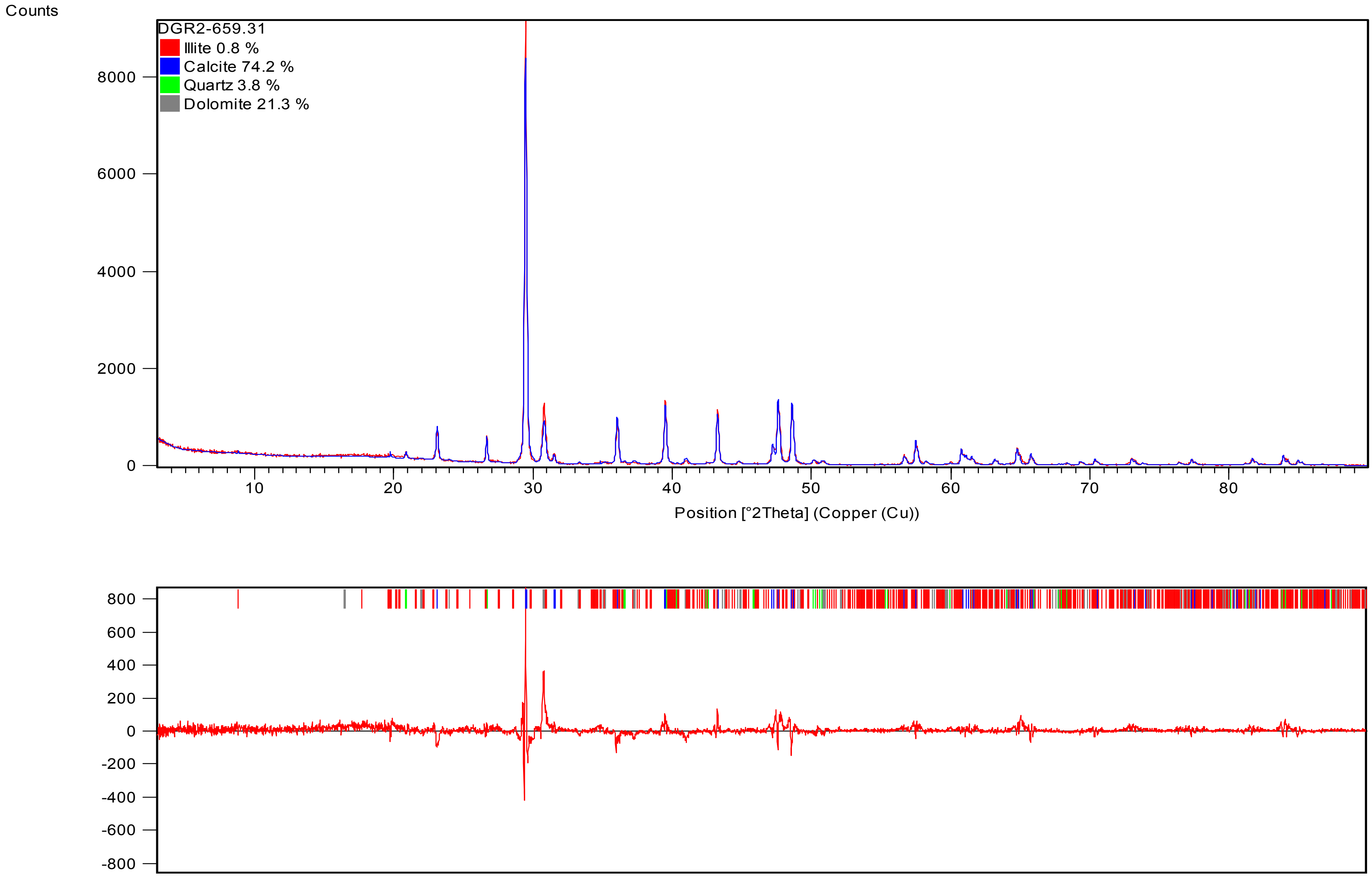

Counts
DGR2-606.62
Quartz 33.5 %
Illite 23.3 %
Clinochlore 8.0 %
Calcite 15.9 %
Halite 1.4 %
Dolomite 18.0 %
3000
2000
1000
0
10
20
30
40
50
60
70
80
Position [°2Theta] (Copper (Cu))

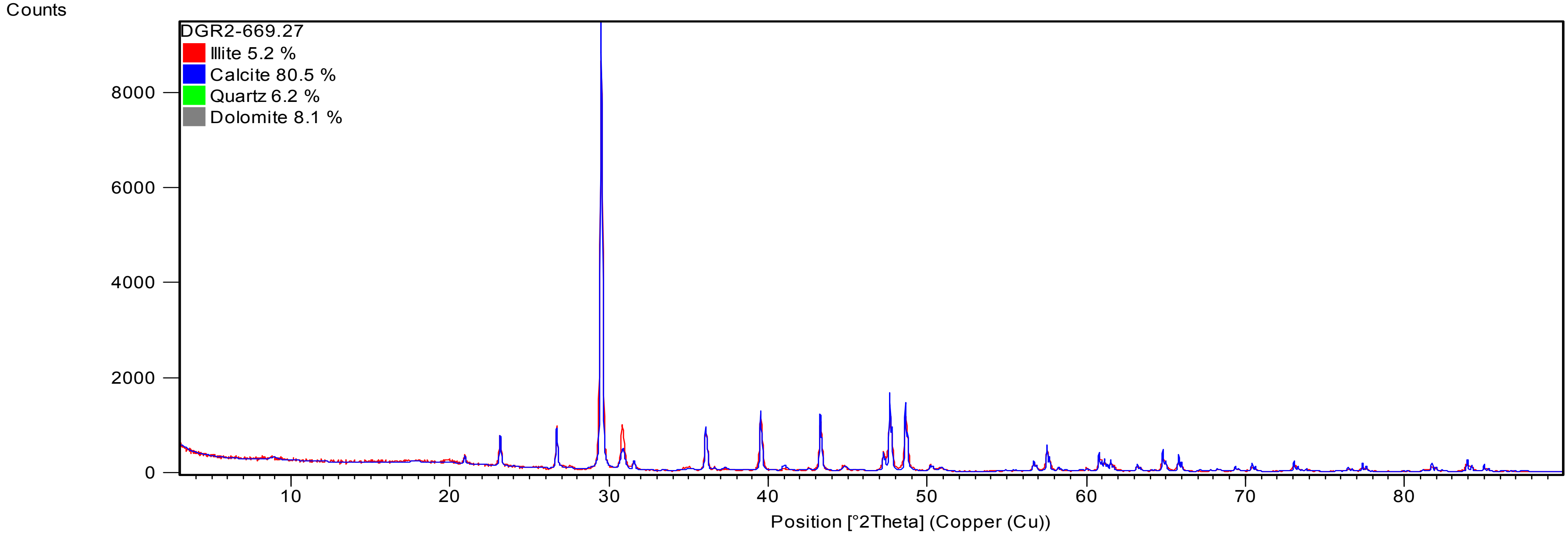

2000
1000
0
-1000
-2000

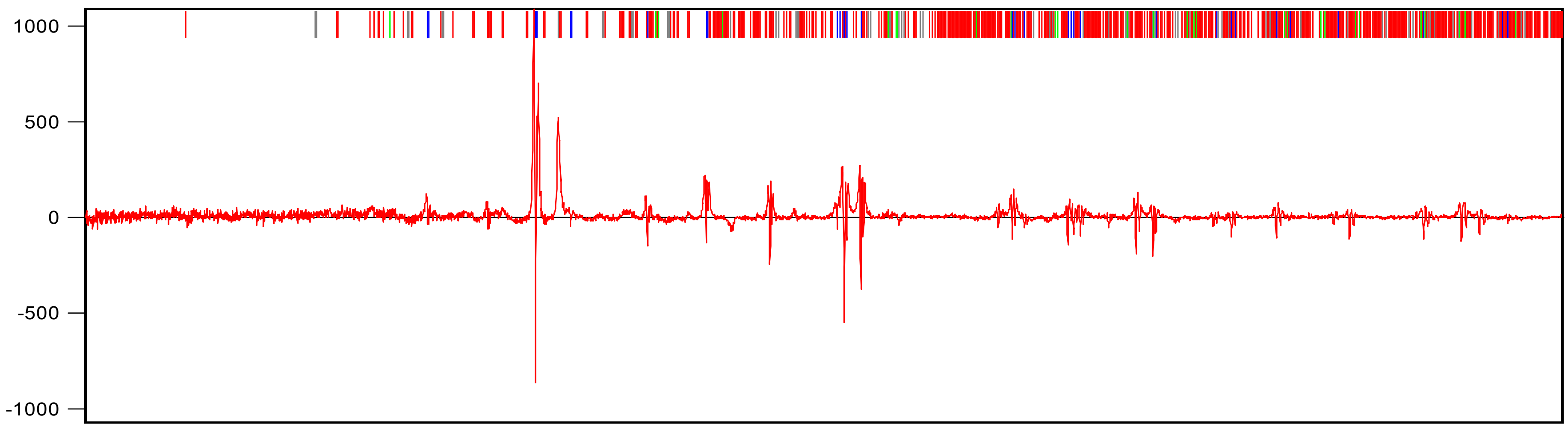

Counts
DGR2-606.96
Calcite 3.5 %
Dolomite 7.9 %
Quartz 43.1 %
Illite 31.6 %
Clinochlore 12.2 %
Pyrite 1.8 %
4000
2000
0
10
20
30
40
50
60
70
80
Position [°2Theta] (Copper (Cu))
300
200
100
0
-100
-200
-300

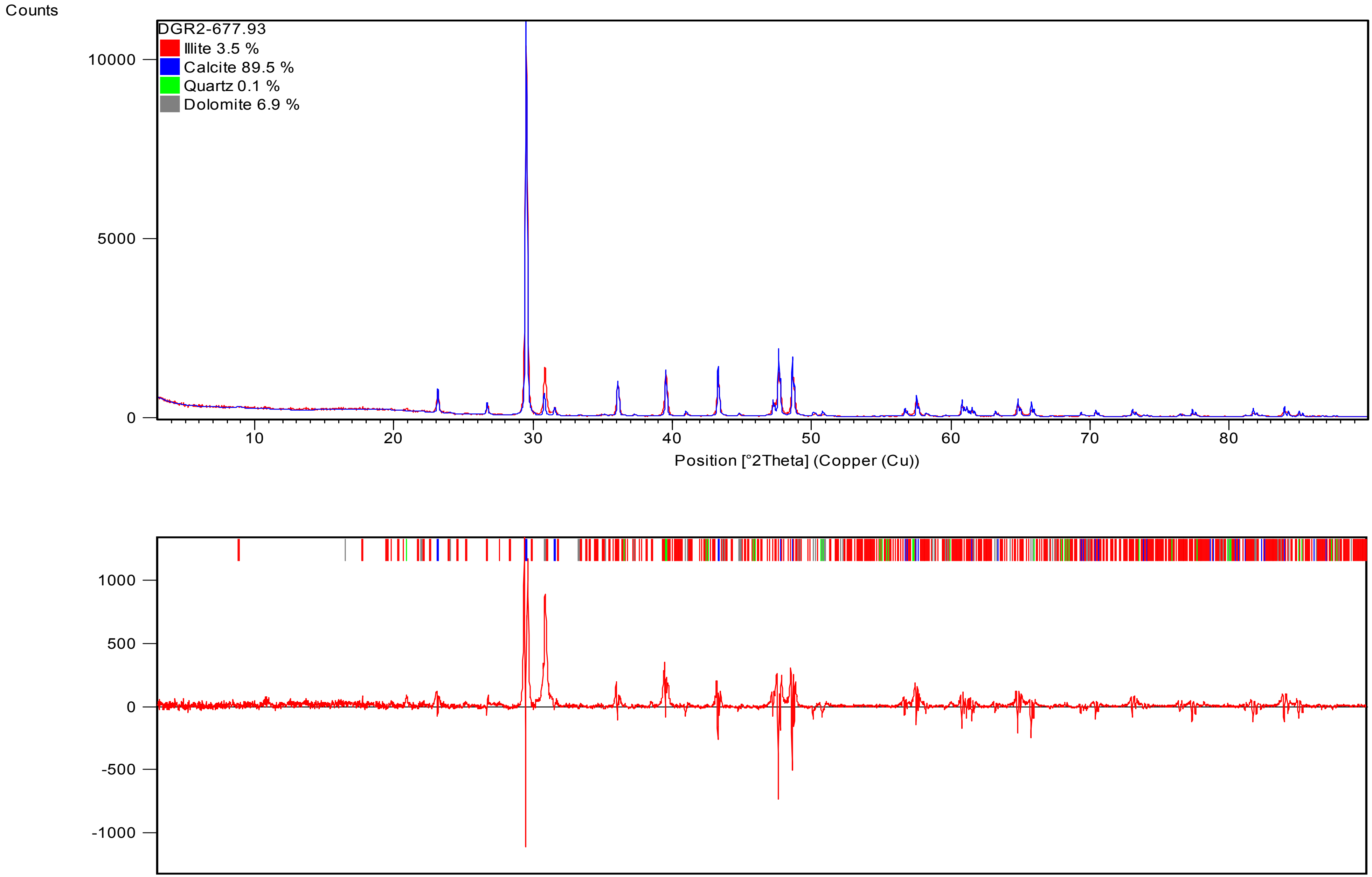

Counts
DGR2-626.29
Calcite 4.1 %
Dolomite 7.8 %
Quartz 45.2 %
Illite 31.6 %
Clinochlore 9.9 %
Pyrite 1.4 %
4000
3000
2000
1000
0
10
20
30
40
50
60
70
80
Position [°2Theta] (Copper (Cu))
400
300
200
100
0
-100
-200
-300
-400

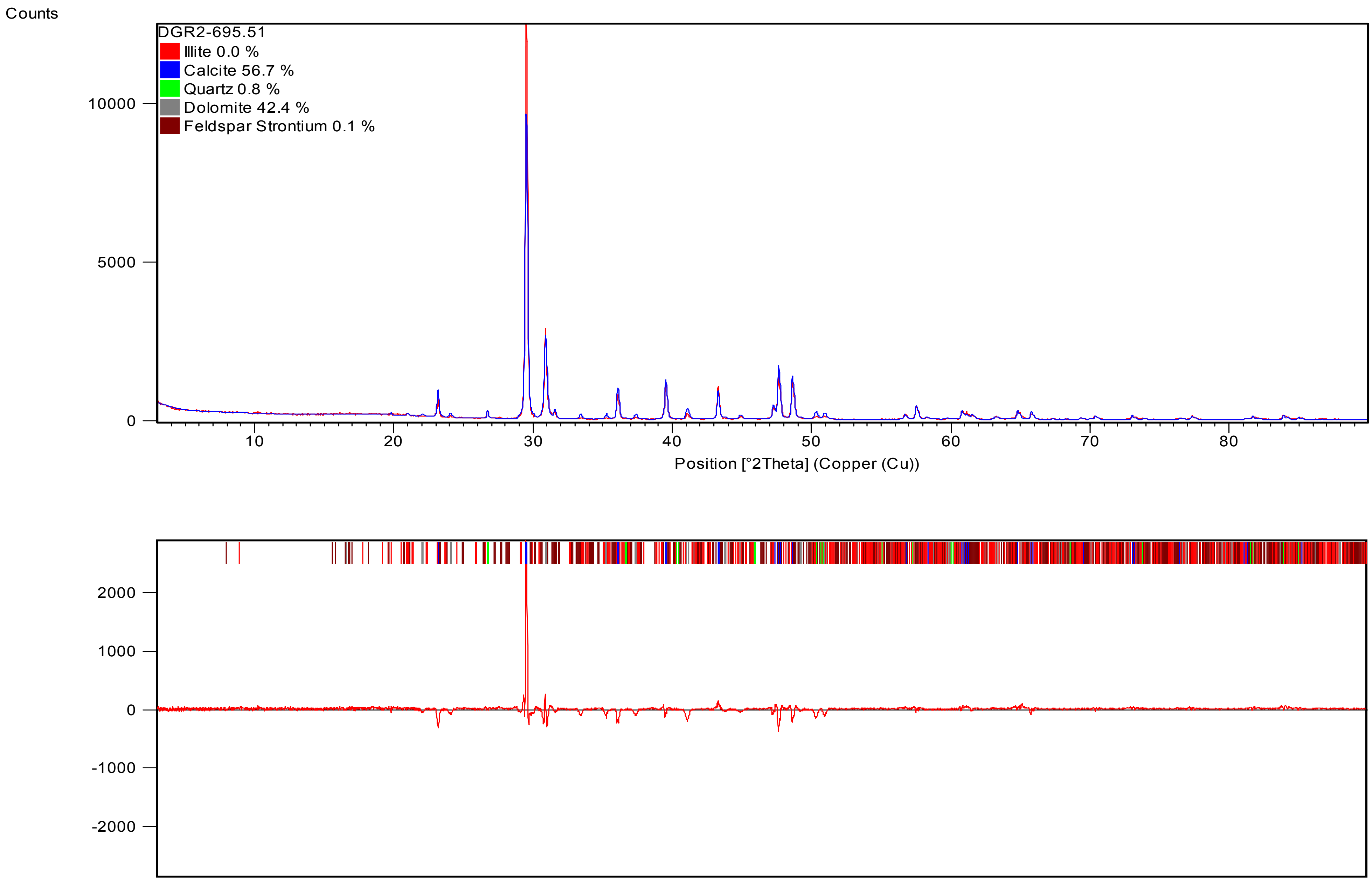

Counts
DGR2-644.49
Calcite 11.5 %
Dolomite 2.2 %
Quartz 47.2 %
Illite 27.8 %
Clinochlore 8.5 %
Pyrite 2.8 %
4000
2000
0
10
20
30
40
50
60
70
80
Position [°2Theta] (Copper (Cu))
200
100
0
-100
-200

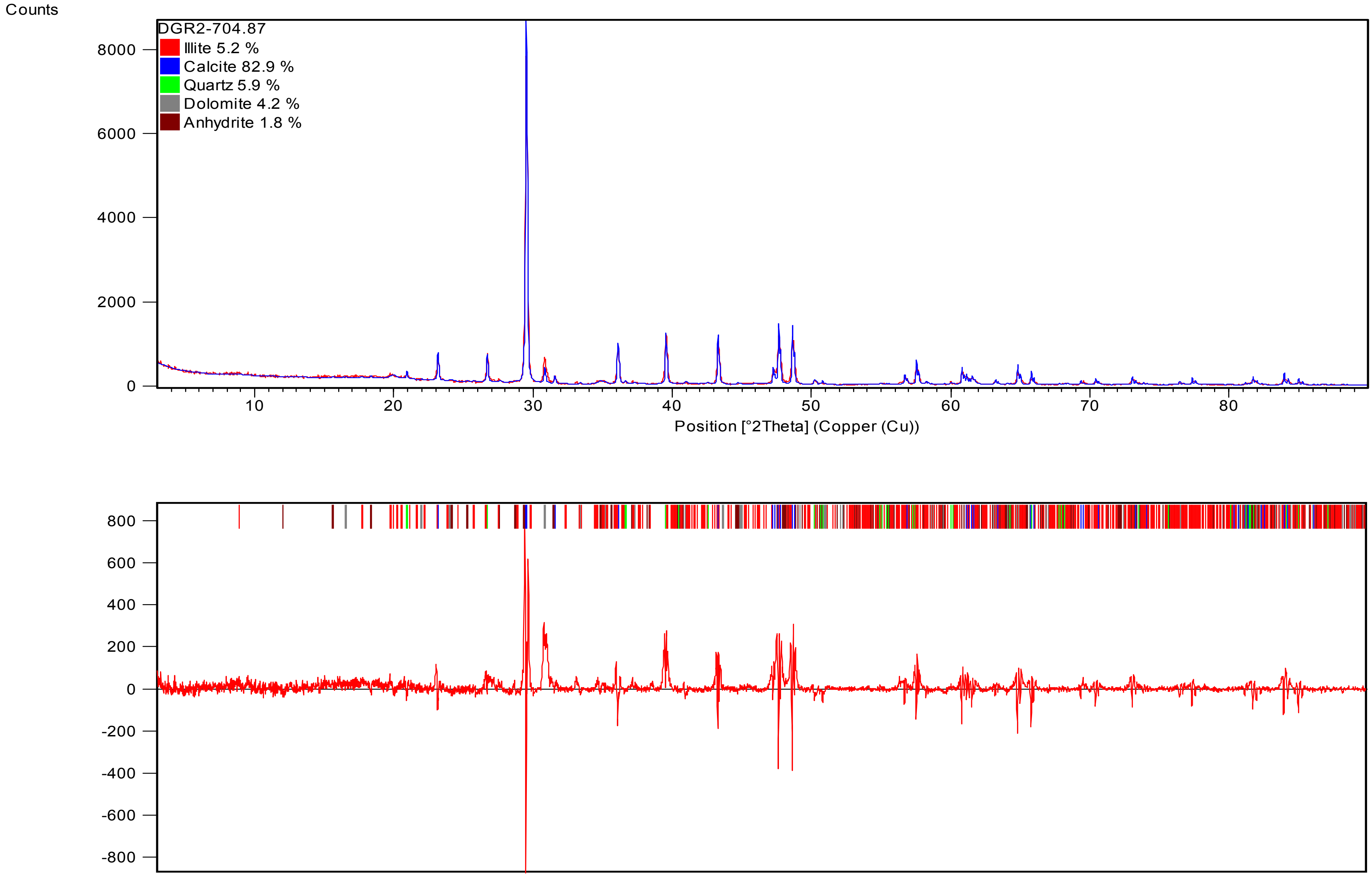

Counts
DGR2-659.31
Illite 0.8 %
Calcite 74.2 %
Quartz 3.8 %
Dolomite 21.3 %
8000
6000
4000
2000
0
10
20
30
40
50
60
70
80
Position [°2Theta] (Copper (Cu))
800
600
400
200
0
-200
-400
-600
-800

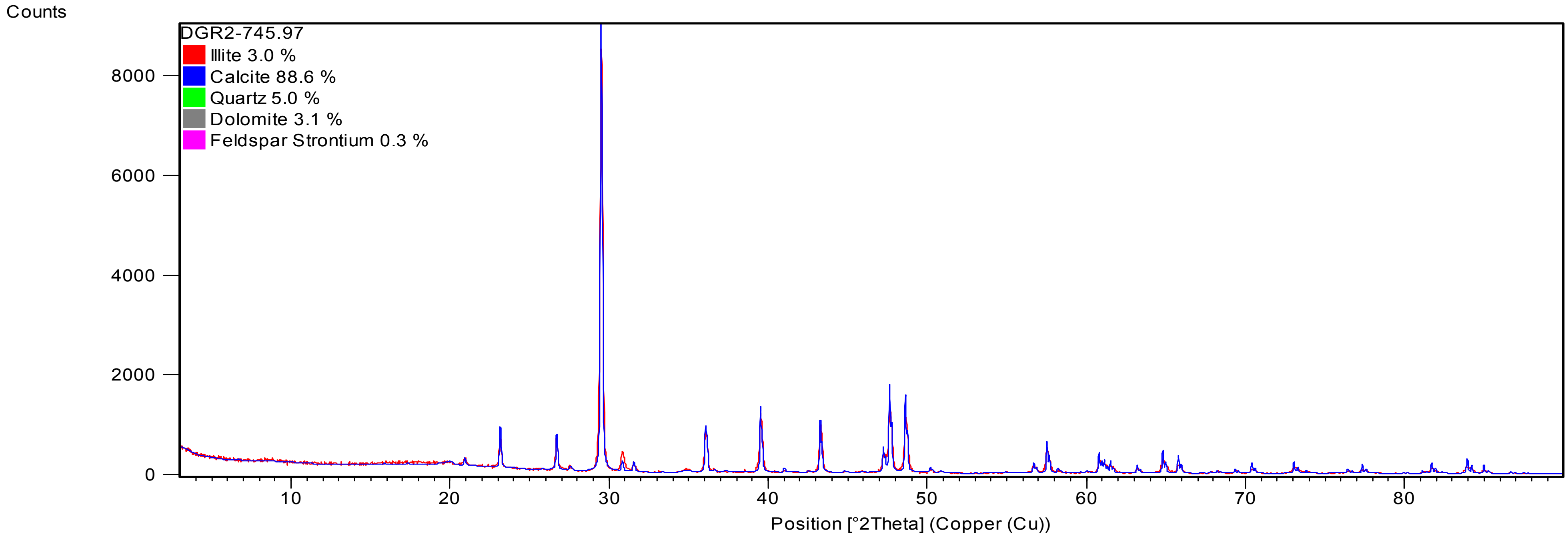

Counts
DGR2-669.27
Illite 5.2 %
Calcite 80.5 %
Quartz 6.2 %
Dolomite 8.1 %
8000
6000
4000
2000
0
10
20
30
40
50
60
70
80
Position [°2Theta] (Copper (Cu))

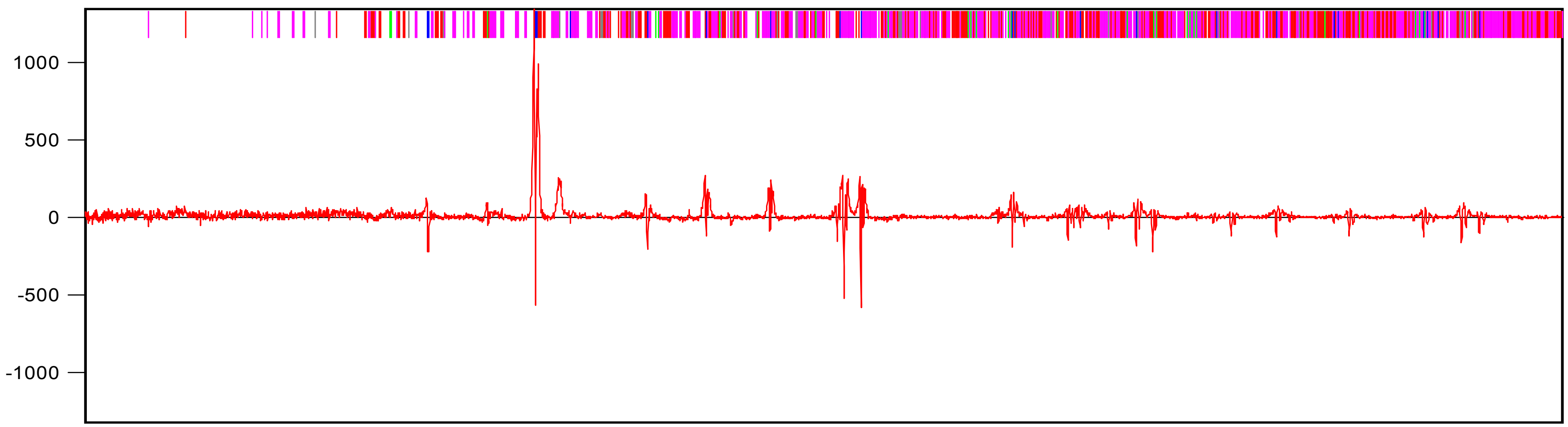

1000
500
0
-500
-1000

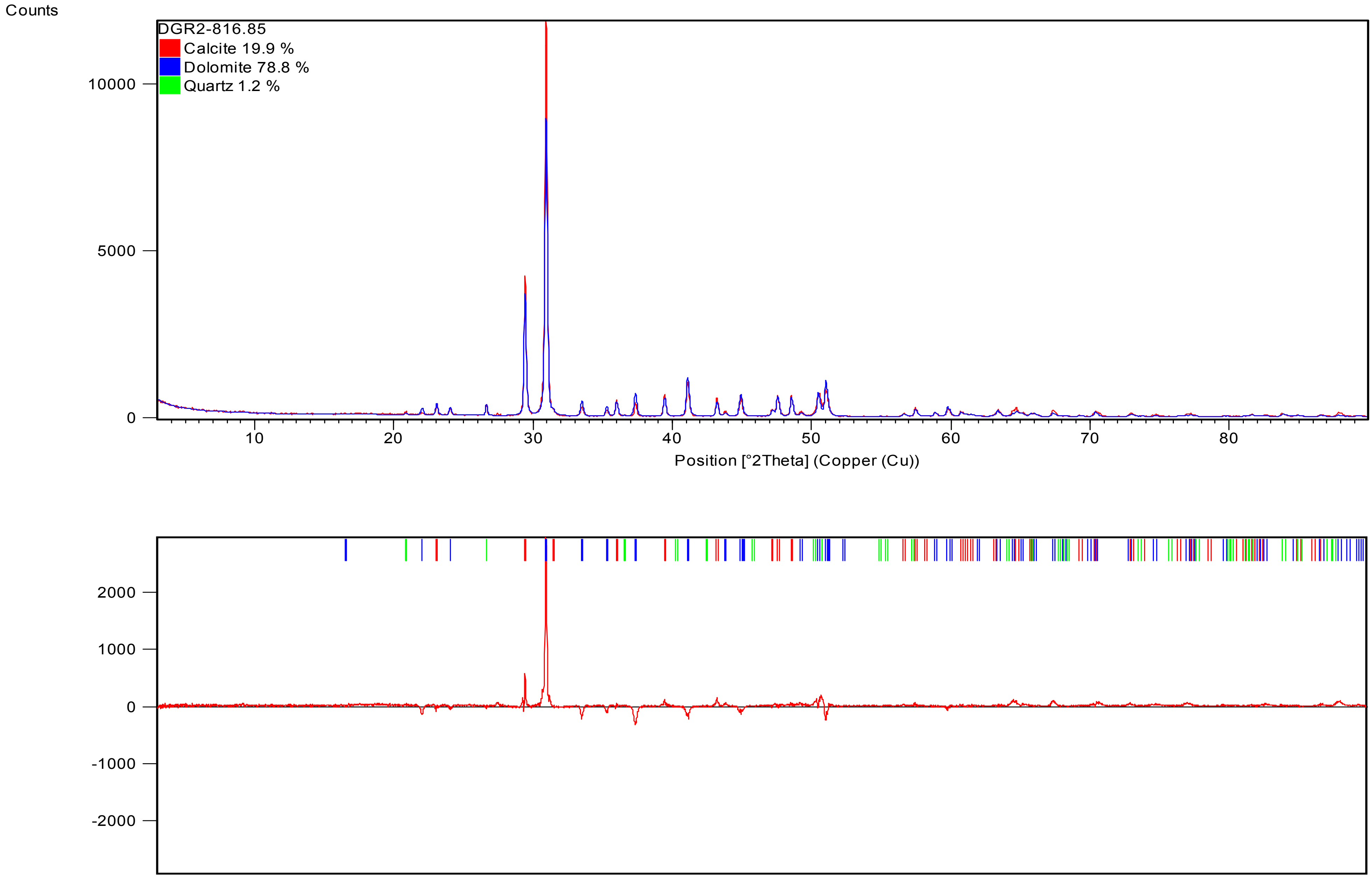

Counts
DGR2-677.93
Illite 3.5 %
Calcite 89.5 %
Quartz 0.1 %
Dolomite 6.9 %
10000
5000
0
10
20
30
40
50
60
70
80
Position [°2Theta] (Copper (Cu))
1000
500
0
-500
-1000

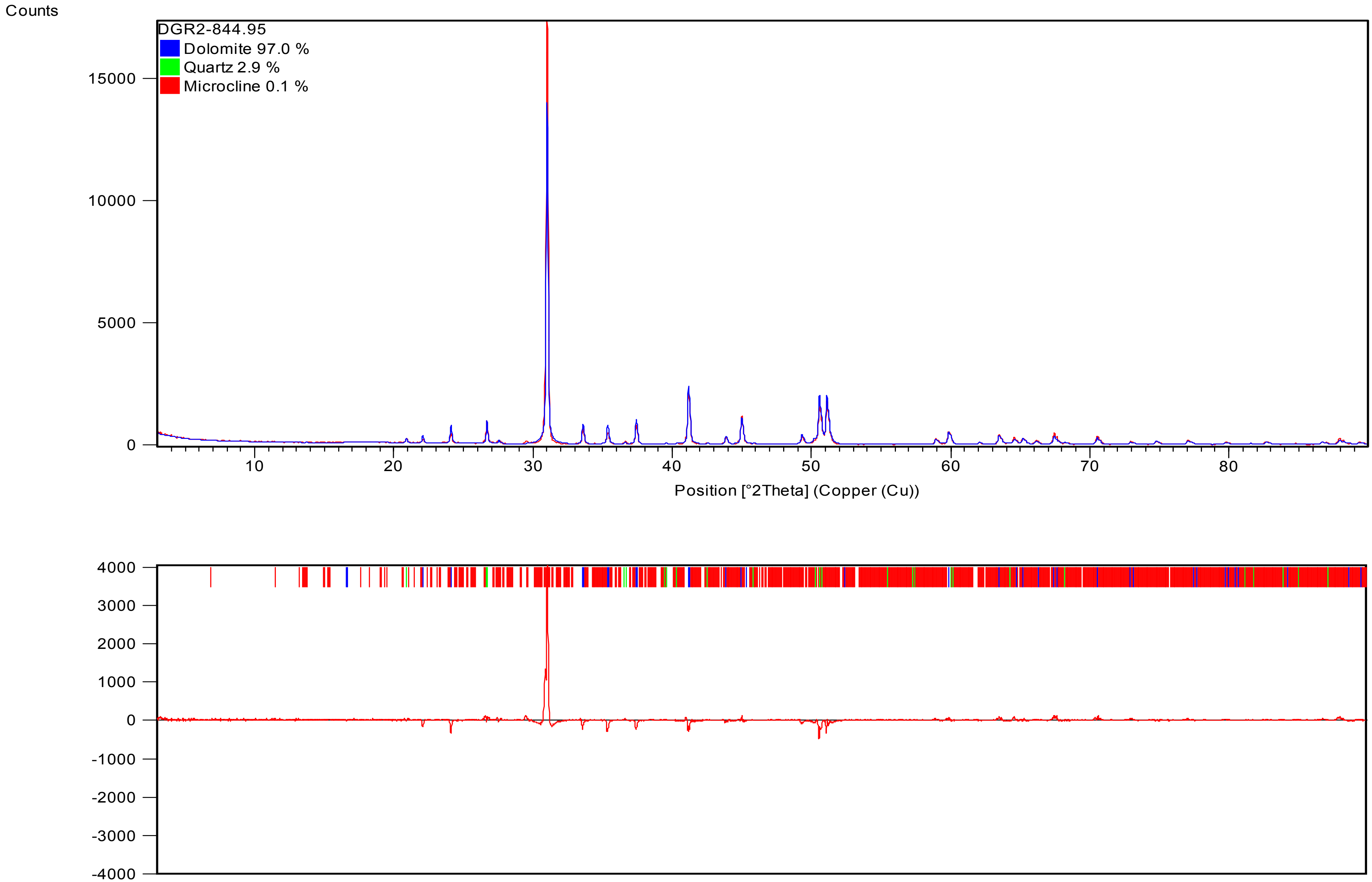

Counts
DGR2-695.51
Illite 0.0 %
Calcite 56.7 %
Quartz 0.8 %
Dolomite 42.4 %
Feldspar Strontium 0.1 %
10000
5000
0
10
20
30
40
50
60
70
80
Position [°2Theta] (Copper (Cu))
2000
1000
0
-1000
-2000


Counts
DGR2-704.87
Illite 5.2 %
Calcite 82.9 %
Quartz 5.9 %
Dolomite 4.2 %
Anhydrite 1.8 %
8000
6000
4000
2000
0
10
20
30
40
50
60
70
80
Position [°2Theta] (Copper (Cu))
800
600
400
200
0
-200
-400
-600
-800


Counts
DGR2-745.97
Illite 3.0 %
Calcite 88.6 %
Quartz 5.0 %
Dolomite 3.1 %
Feldspar Strontium 0.3 %
8000
6000
4000
2000
0
10
20
30
40
50
60
70
80
Position [°2Theta] (Copper (Cu))


1000
500
0
-500
-1000


Counts
DGR2-816.85
Calcite 19.9 %
Dolomite 78.8 %
Quartz 1.2 %
10000
5000
0
10
20
30
40
50
60
70
80
Position [°2Theta] (Copper (Cu))
2000
1000
0
-1000
-2000

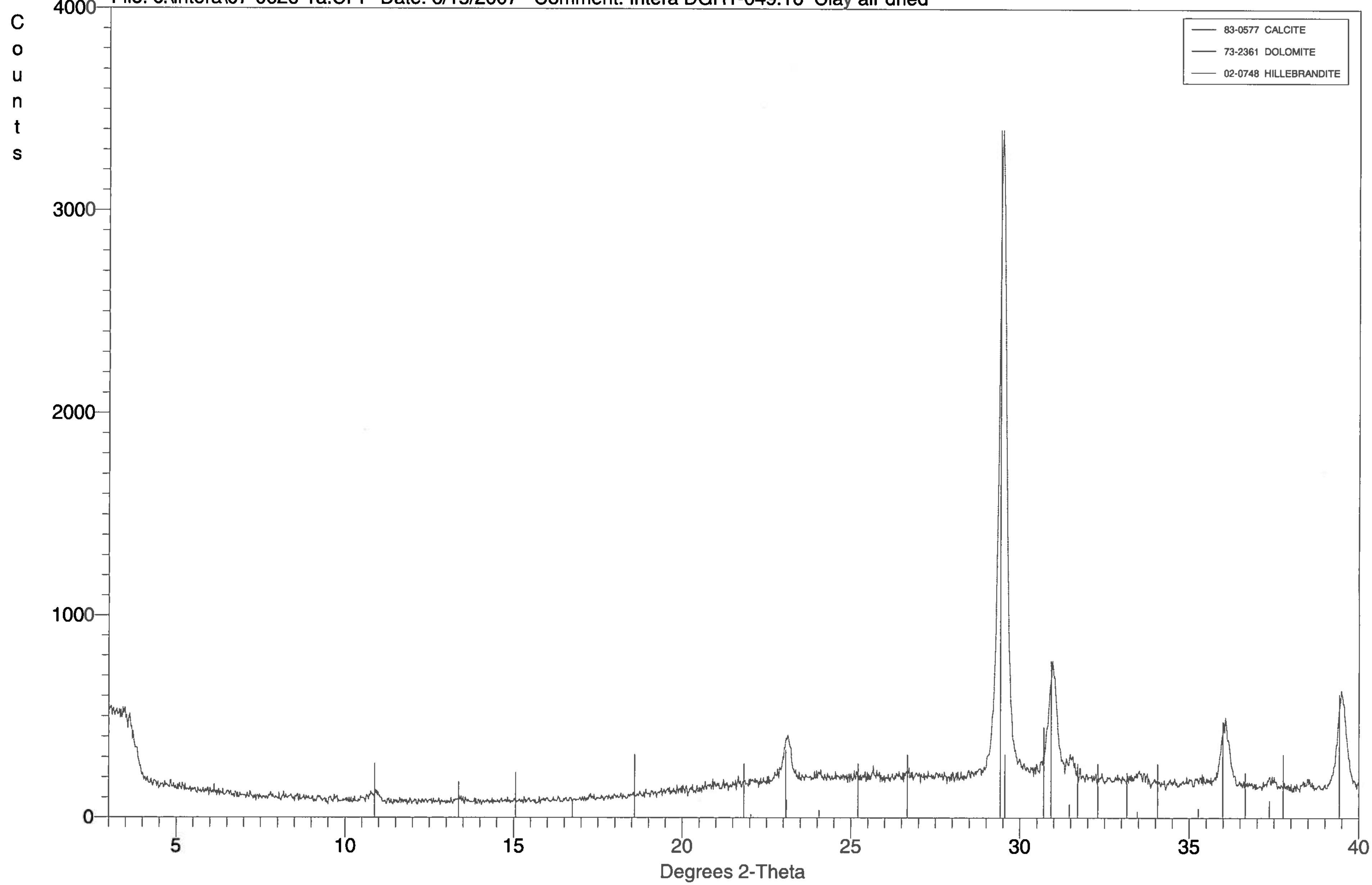

Counts
DGR2-844.95
Dolomite 97.0 %
Quartz 2.9 %
Microcline 0.1 %
15000
10000
5000
0
10
20
30
40
50
60
70
80
Position [°2Theta] (Copper (Cu))
4000
3000
2000
1000
0
-1000
-2000
-3000
-4000

APPENDIX C

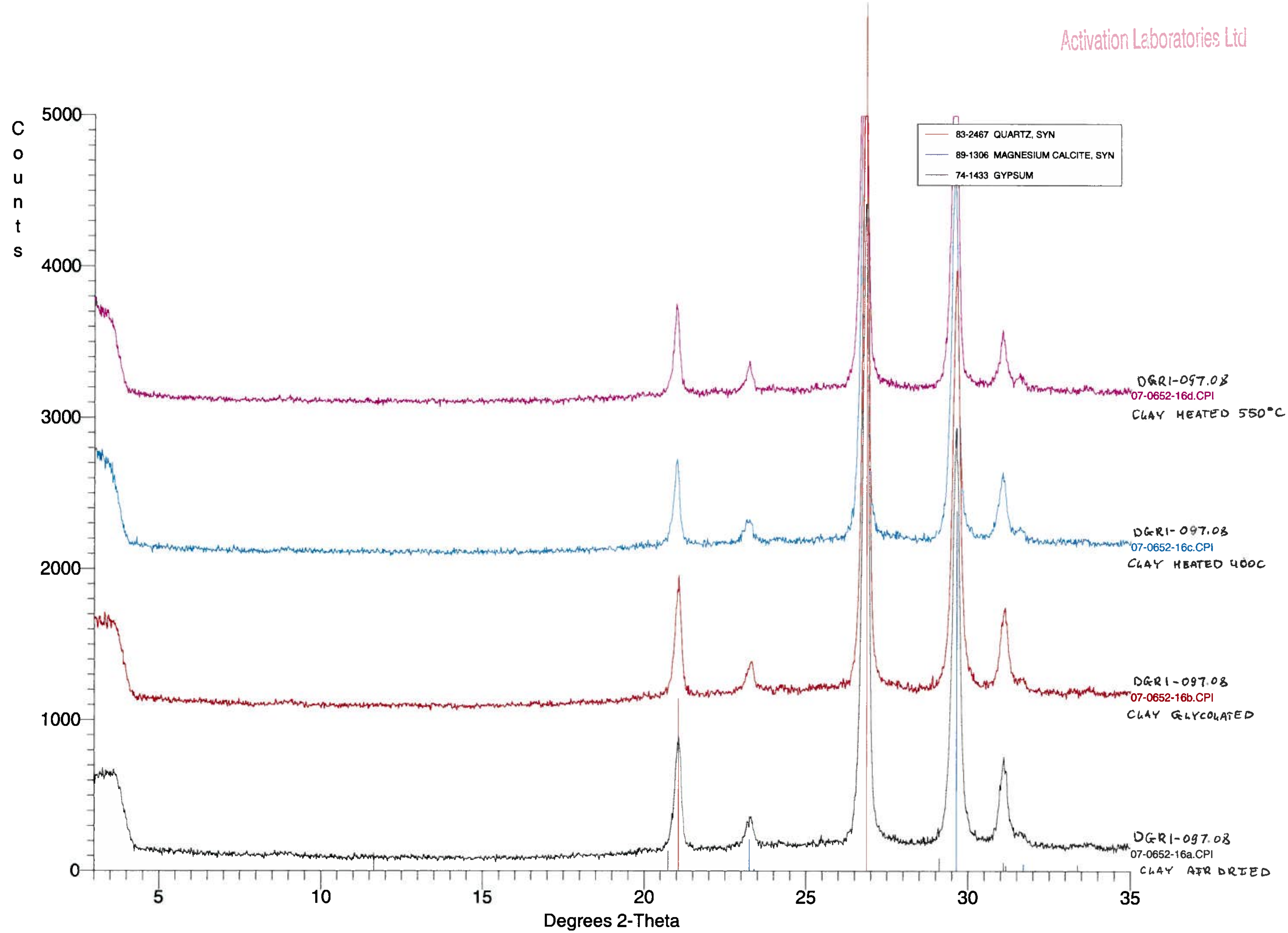
X-Ray Powder Diffractograms of the Clay-Sized Fraction

Activation Laboratories Ltd

File: c:\intera\07-0626-1a.CPI Date: 6/15/2007 Comment: Intera DGR1-049.16 Clay air dried

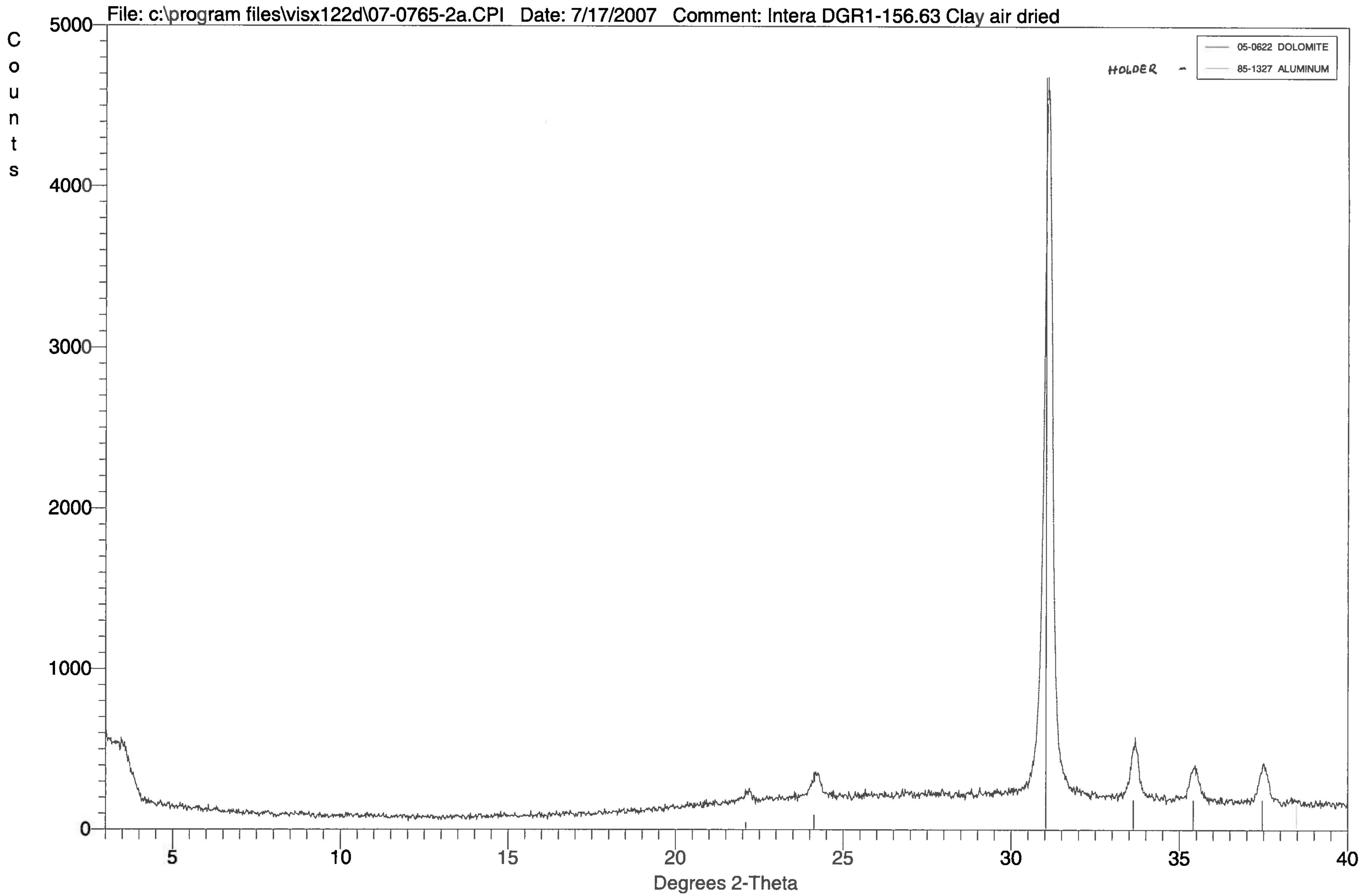


December 13, 2007



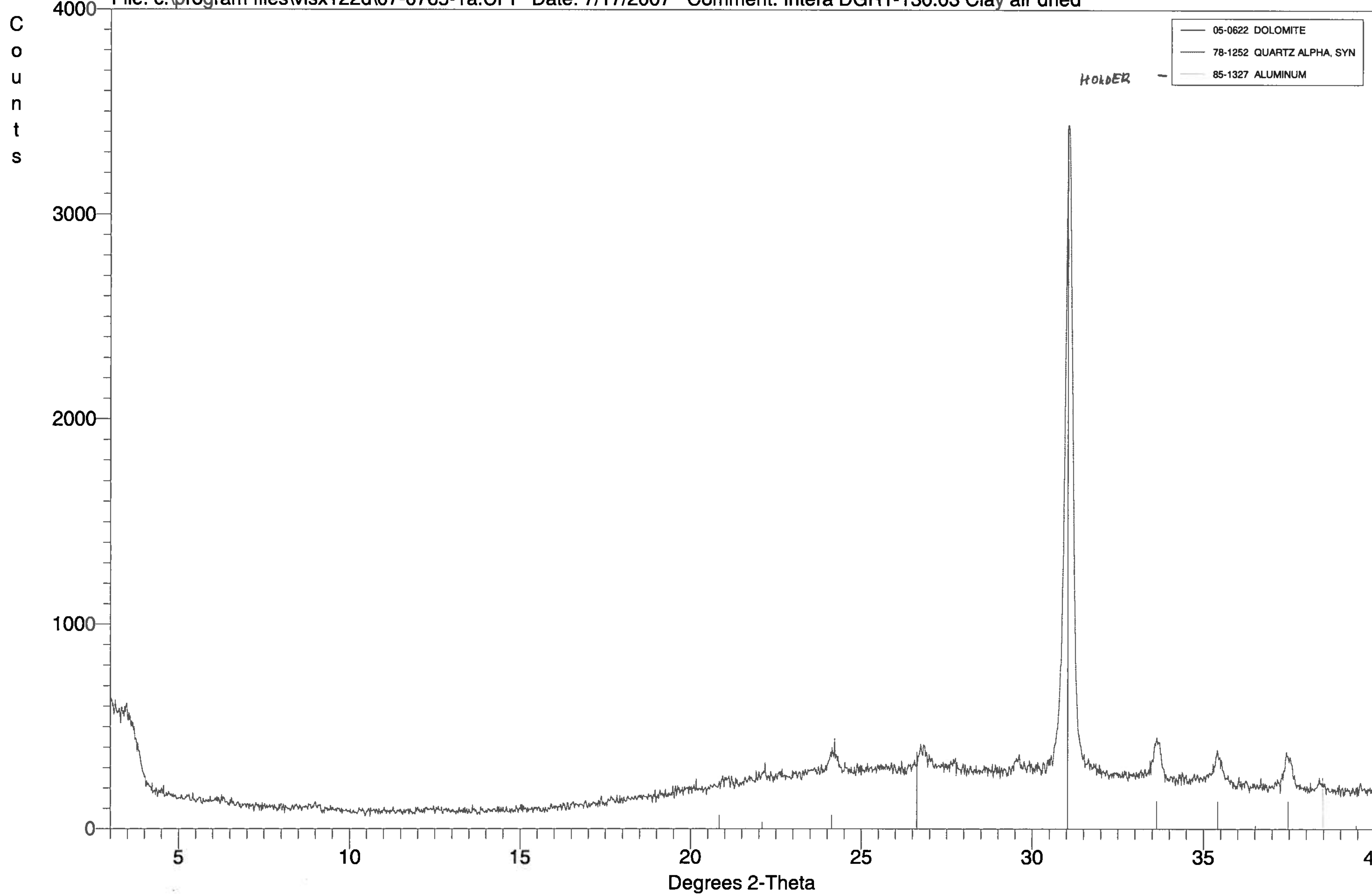
December 13, 2007

Activation Laboratories Ltd

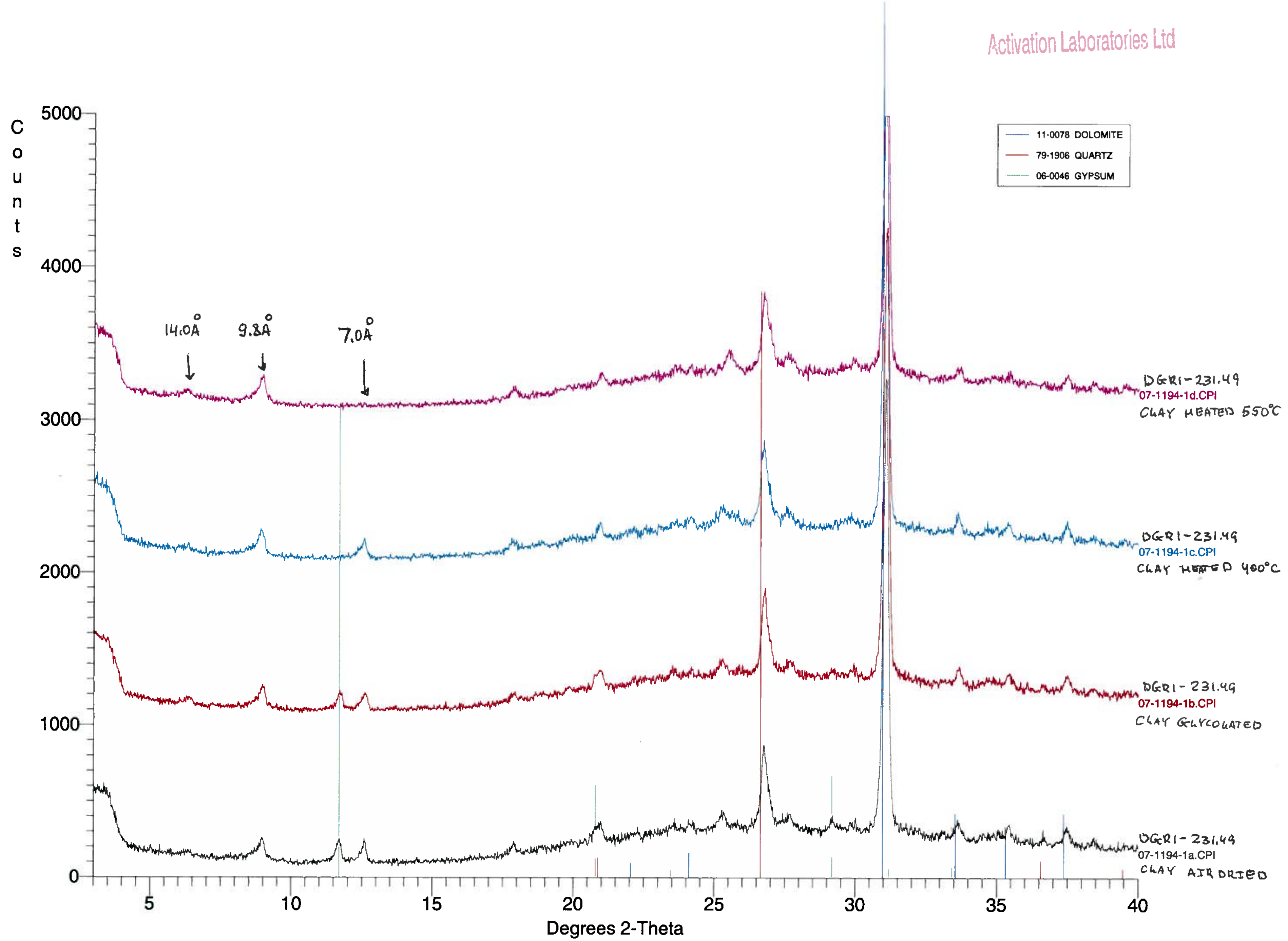


December 13, 2007

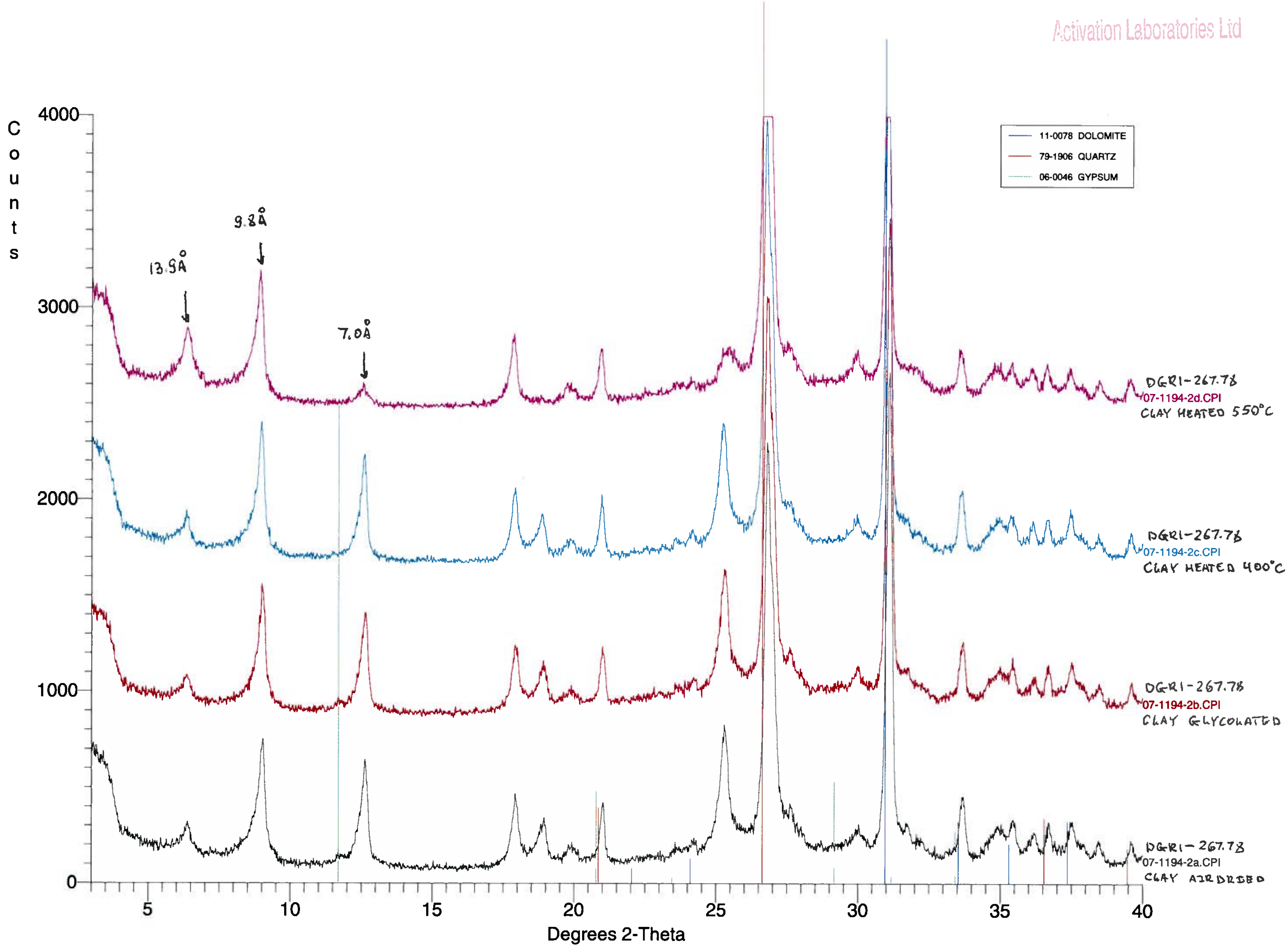
File: c:\program files\visx122d\07-0765-1a.CPI   Date: 7/17/2007   Comment: Intera DGR1-130.03 Clay air dried



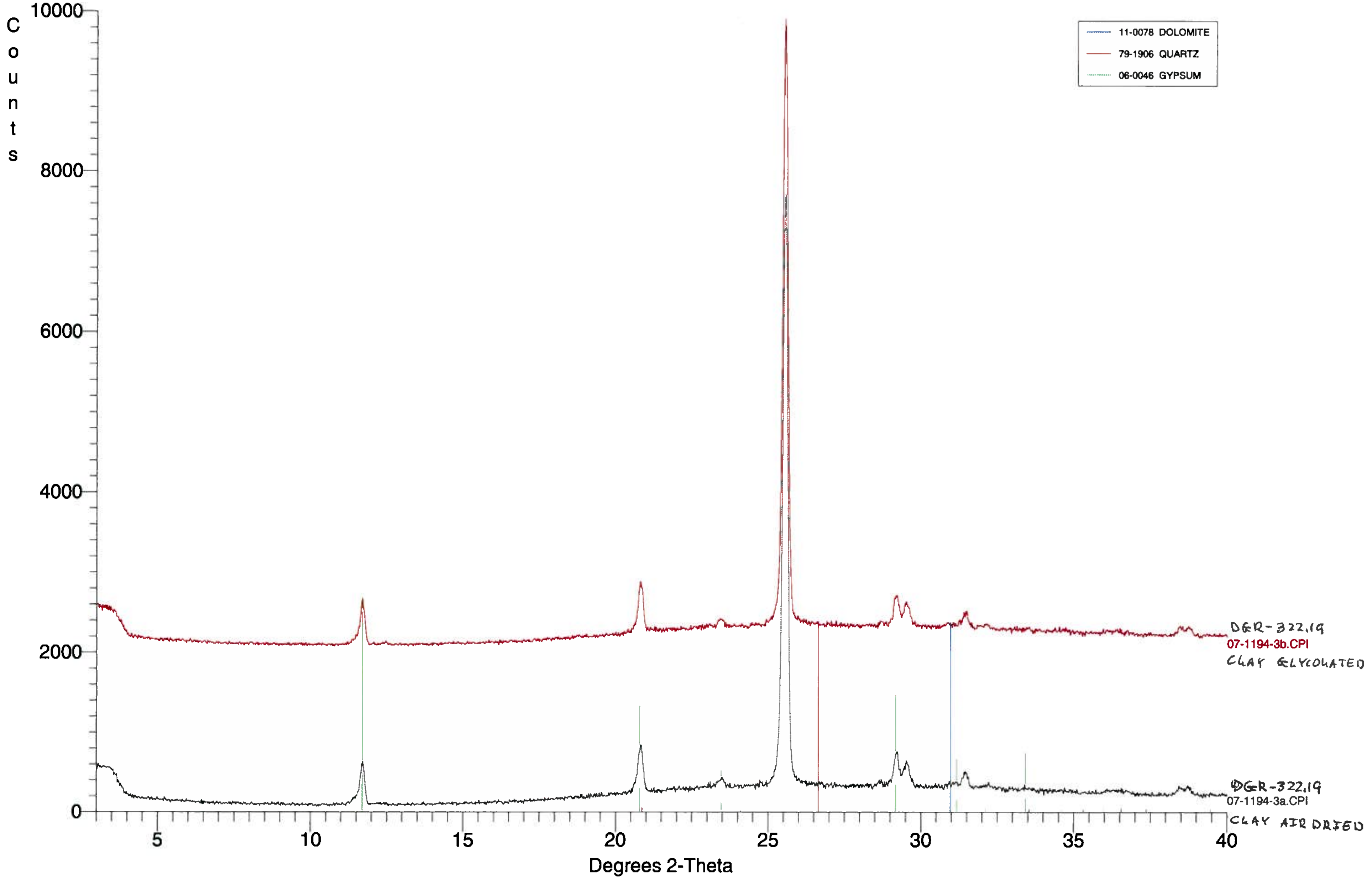
December 13, 2007



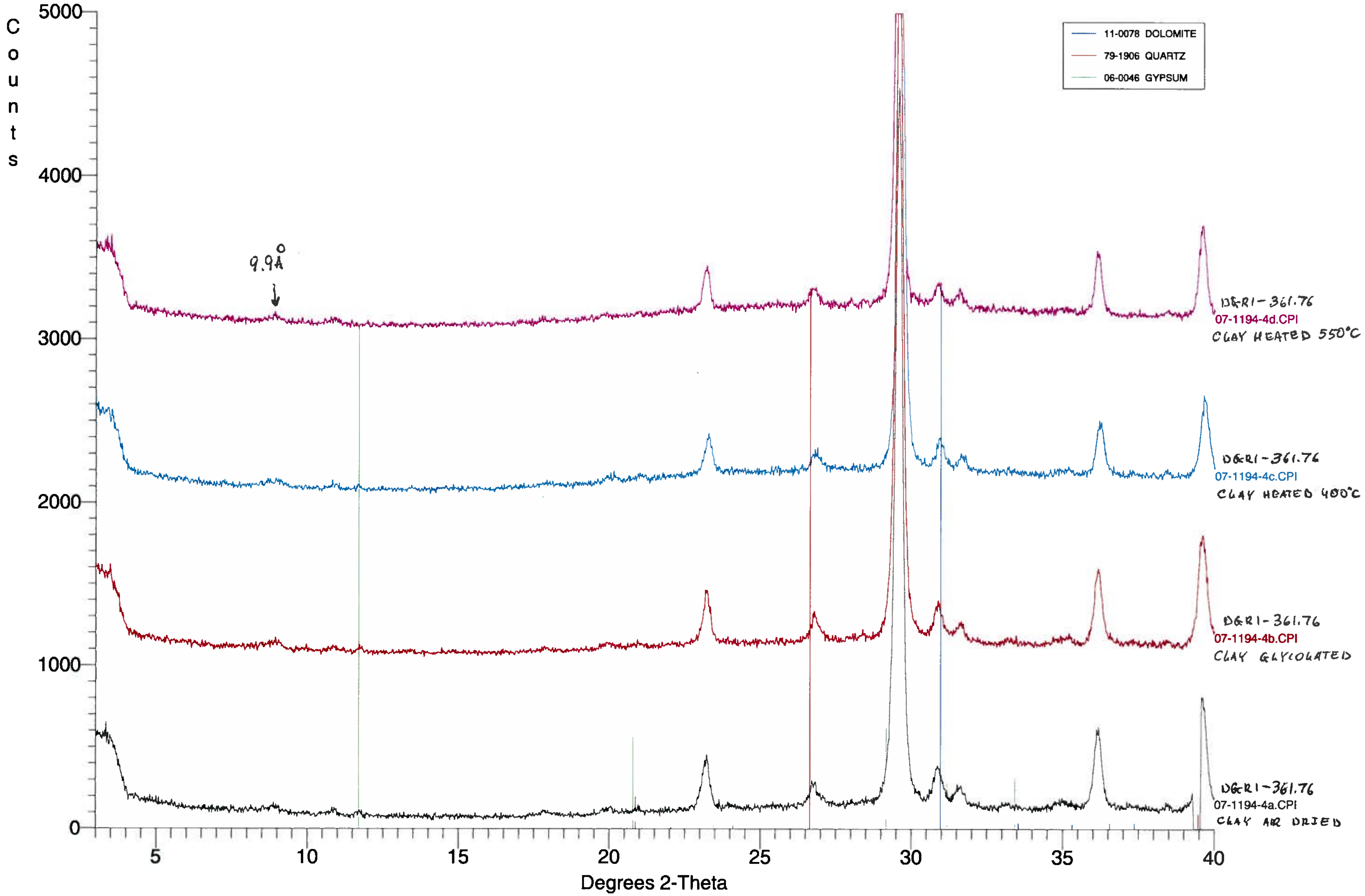
December 13, 2007



December 13, 2007



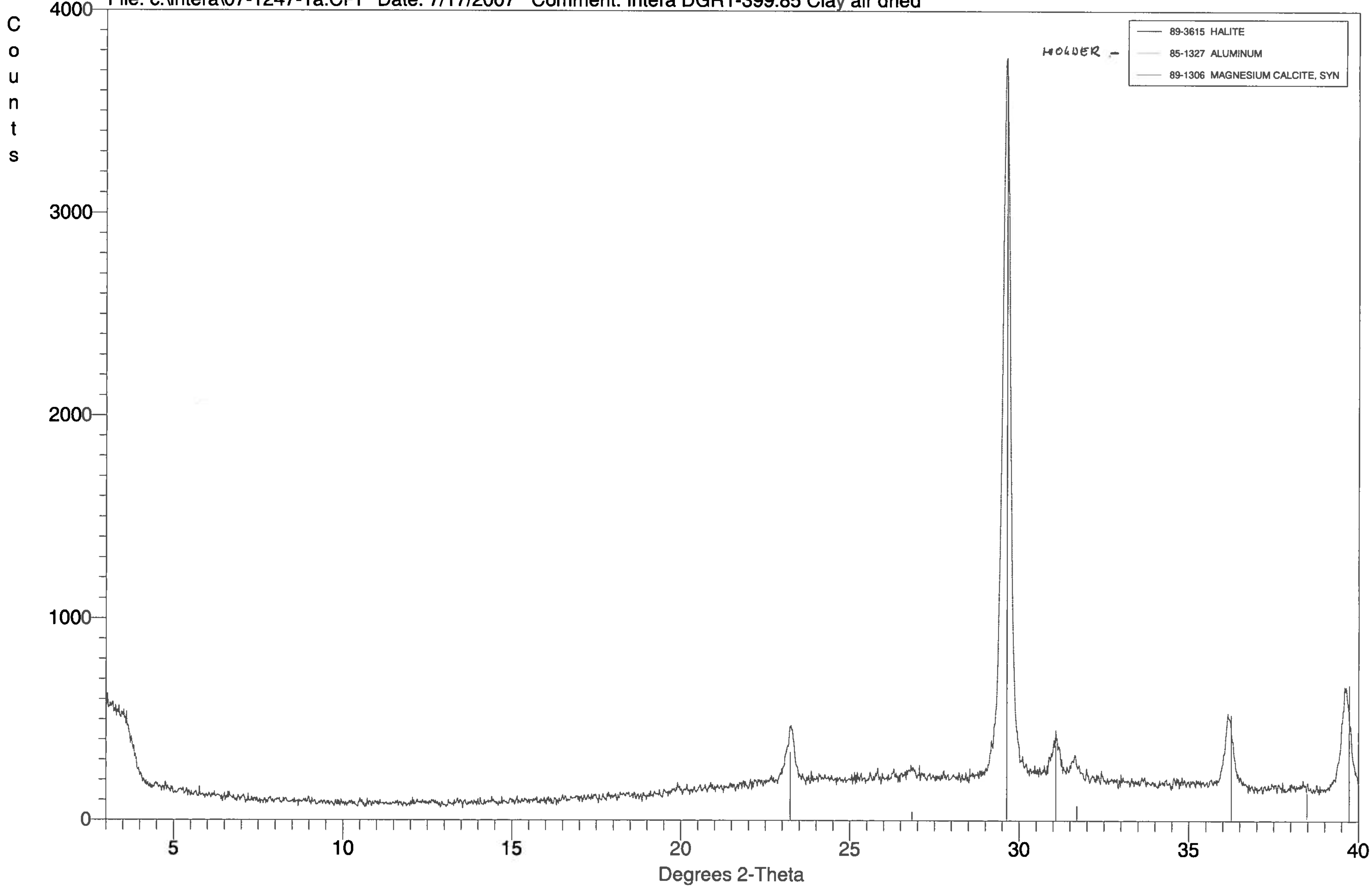
December 13, 2007



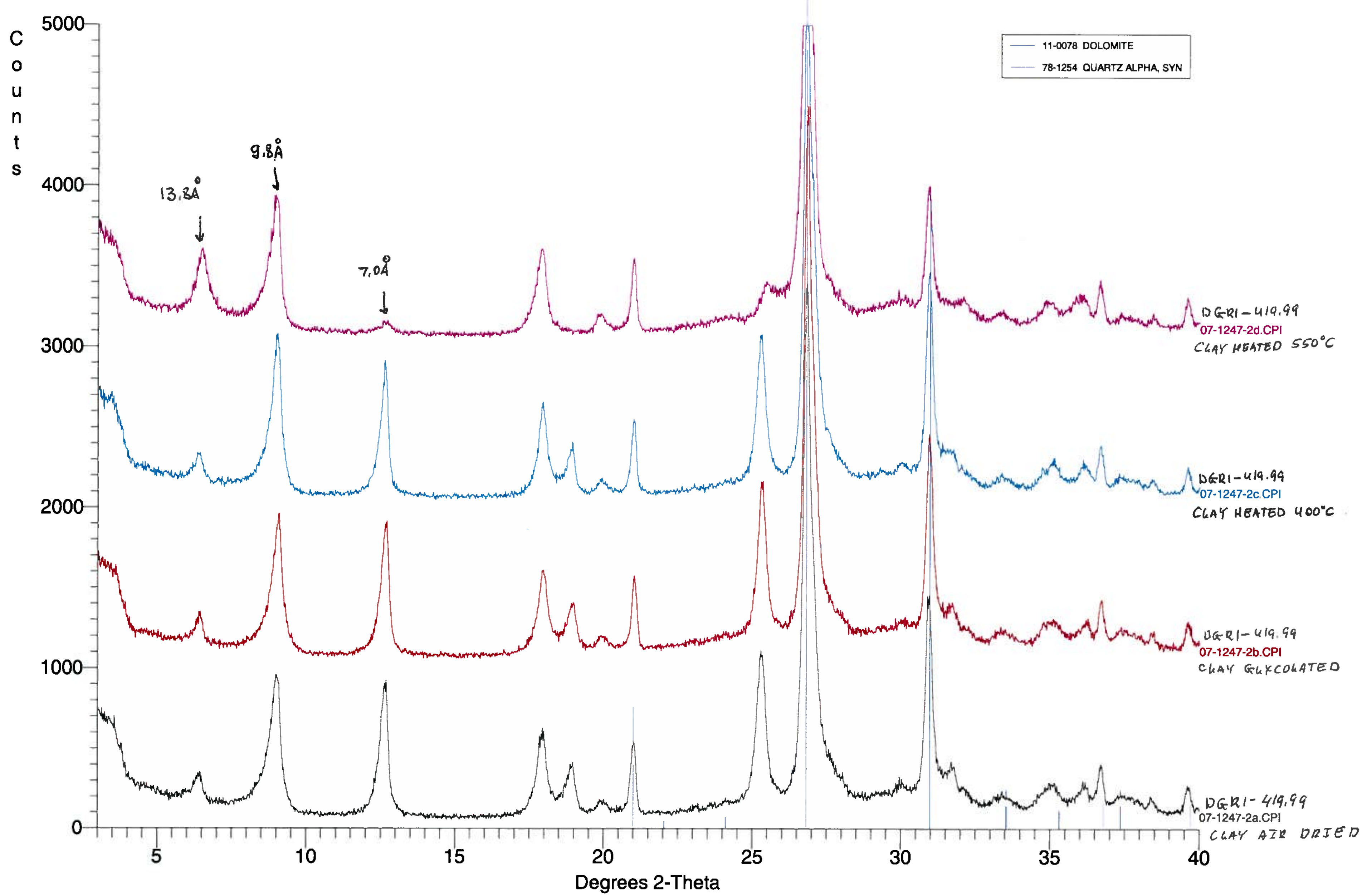
December 13, 2007

Activation Laboratories Ltd

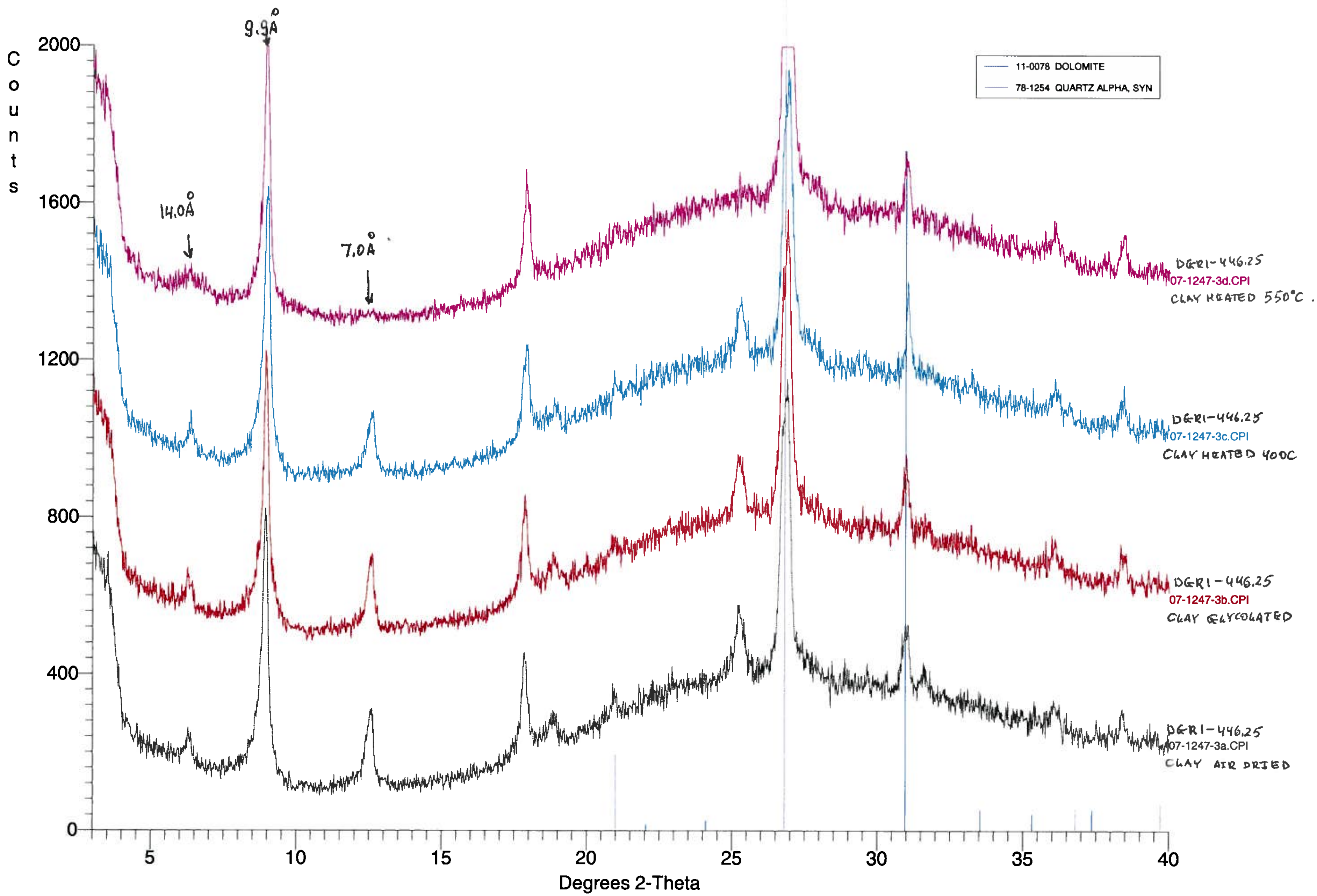
File: c:\intera\07-1247-1a.CPI   Date: 7/17/2007   Comment: Intera DGR1-399.85 Clay air dried



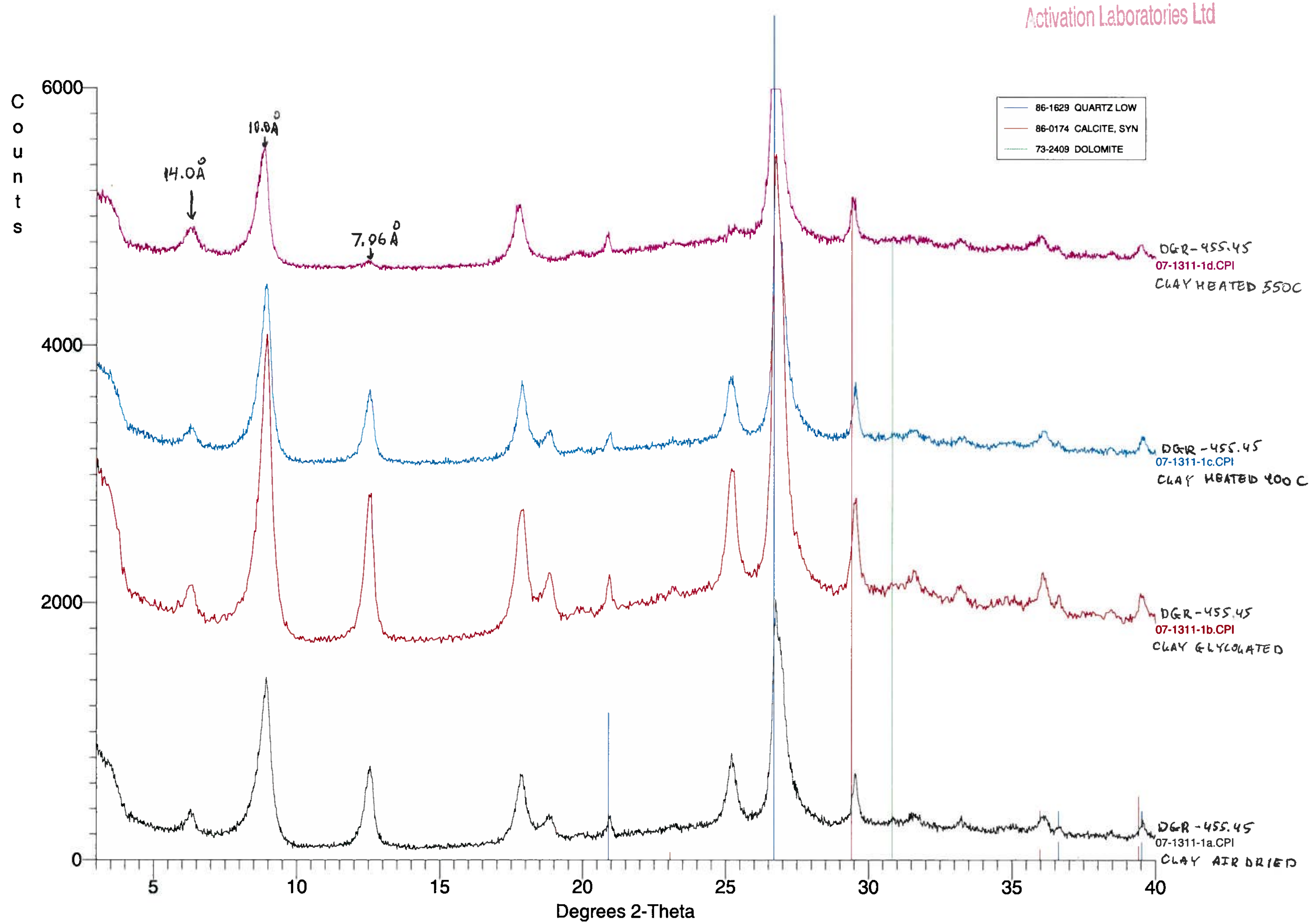
December 13, 2007



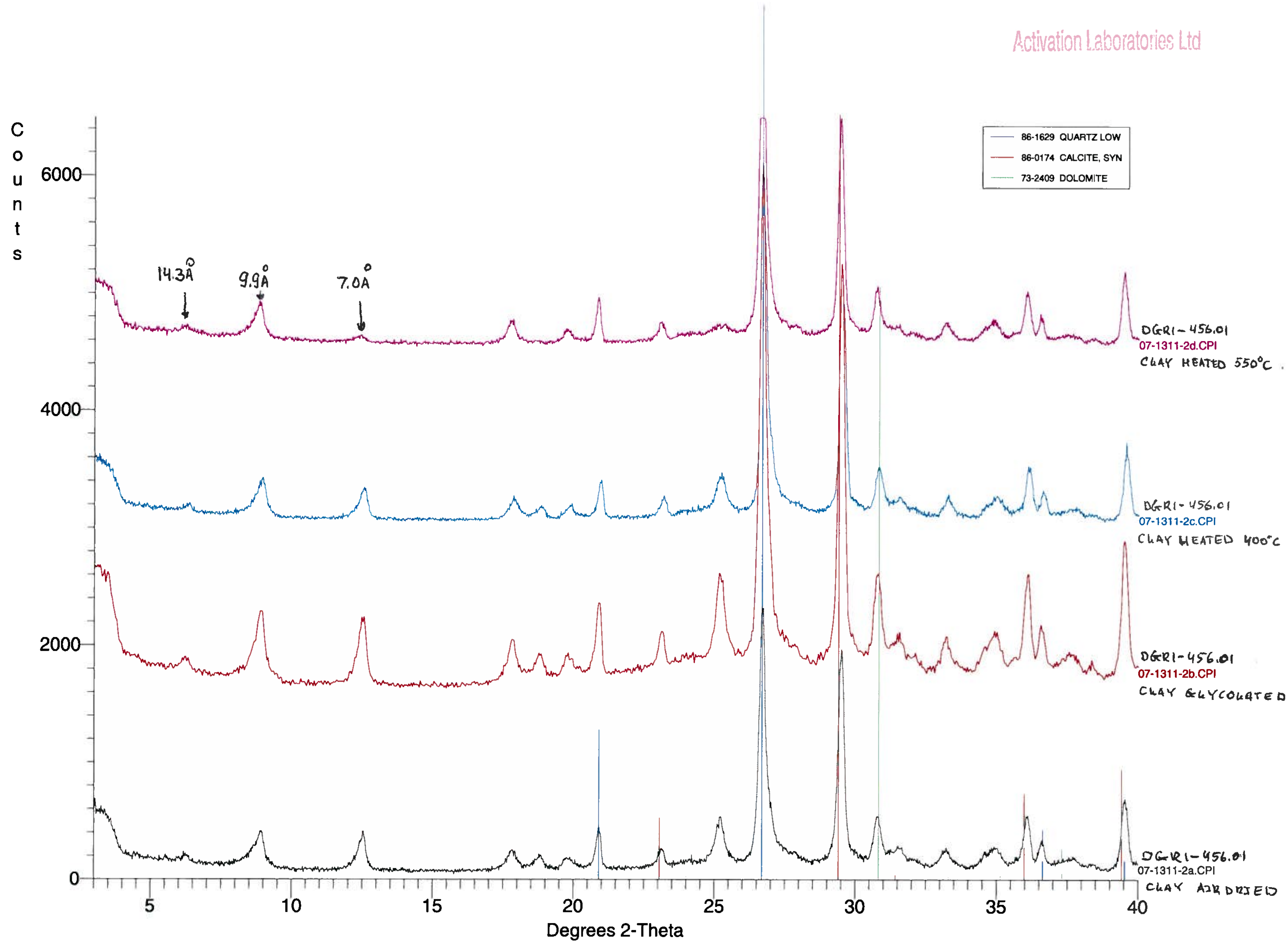
December 13, 2007



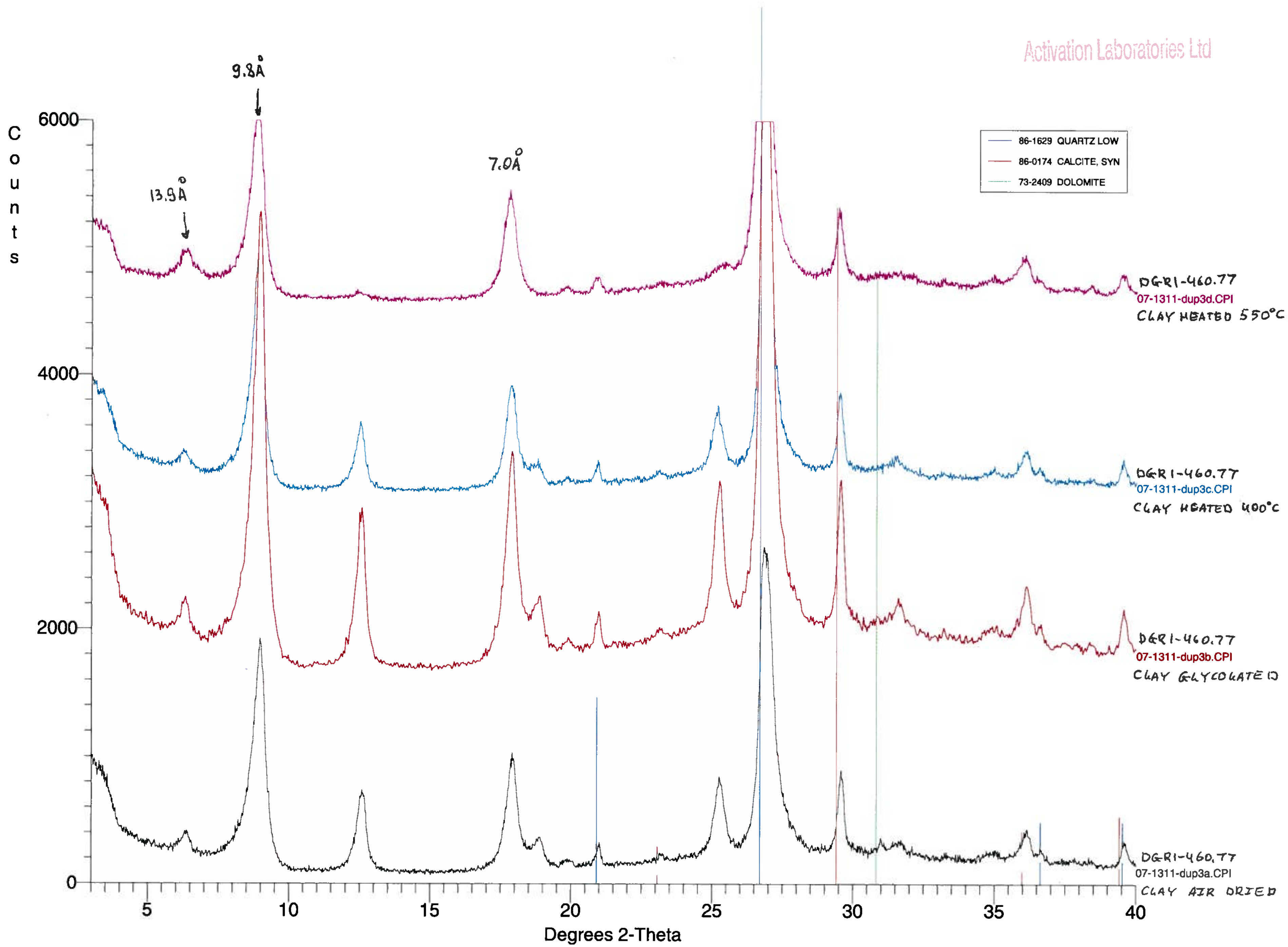
December 13, 2007.



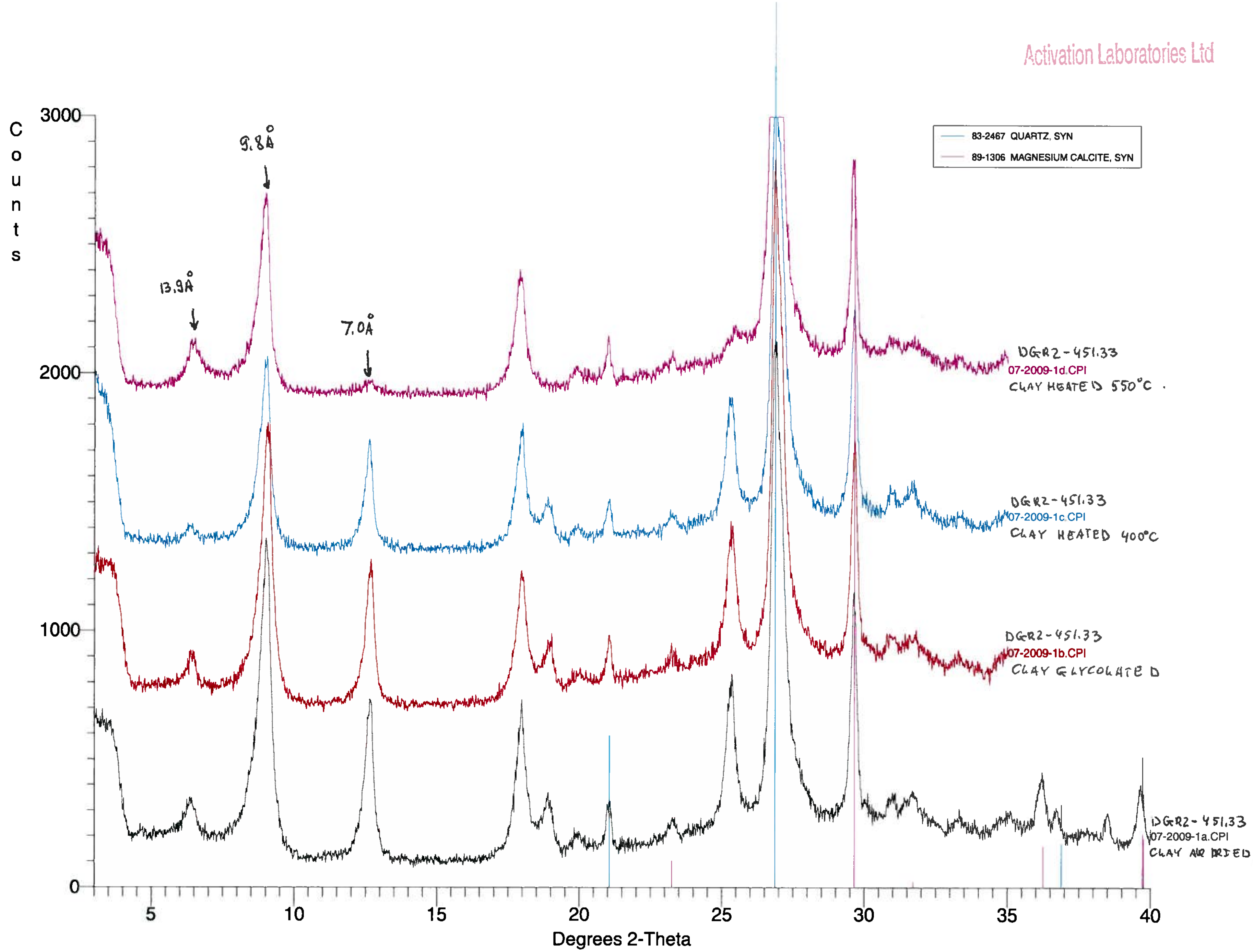
December 14, 2007



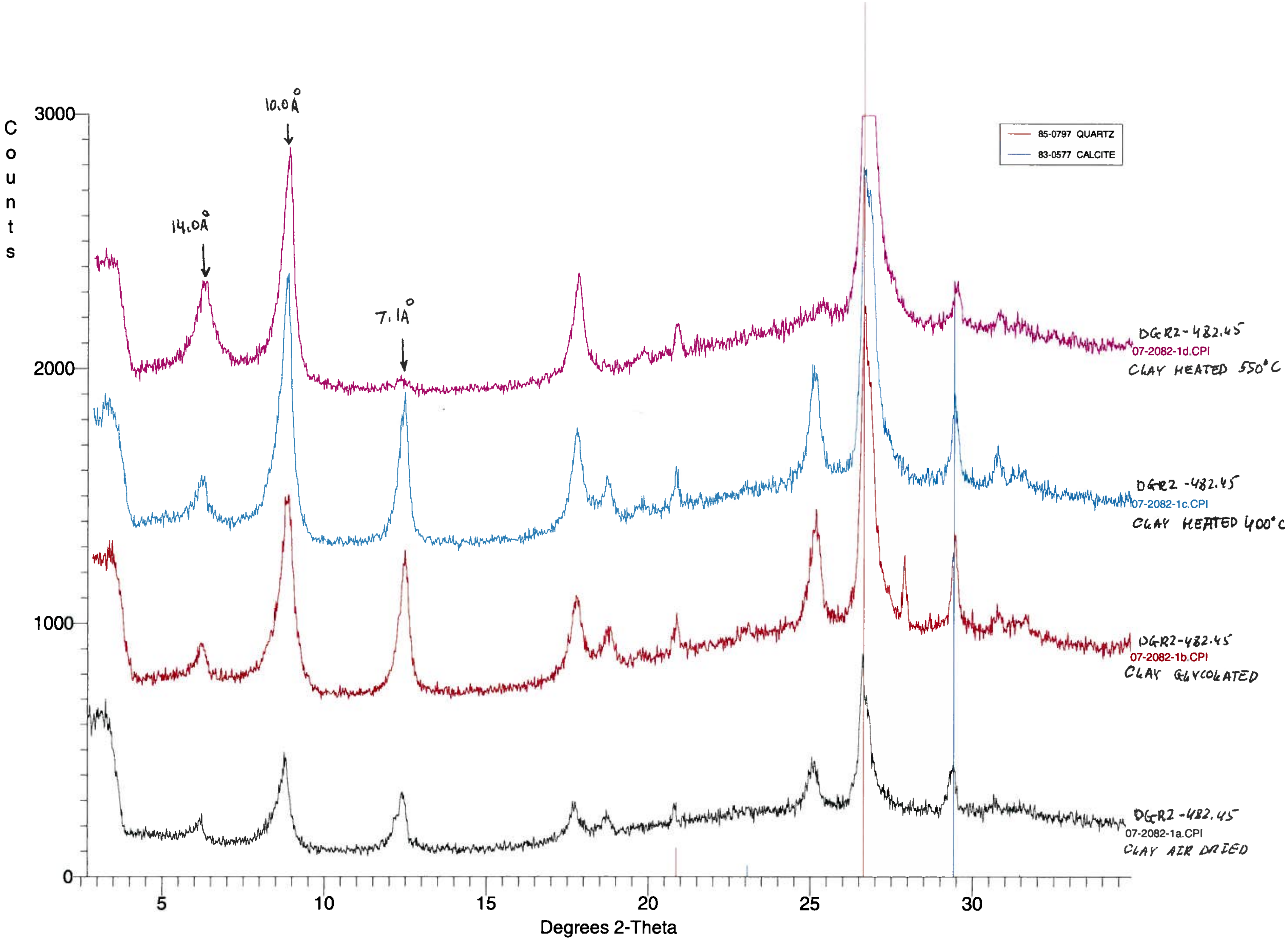
December 13, 2007



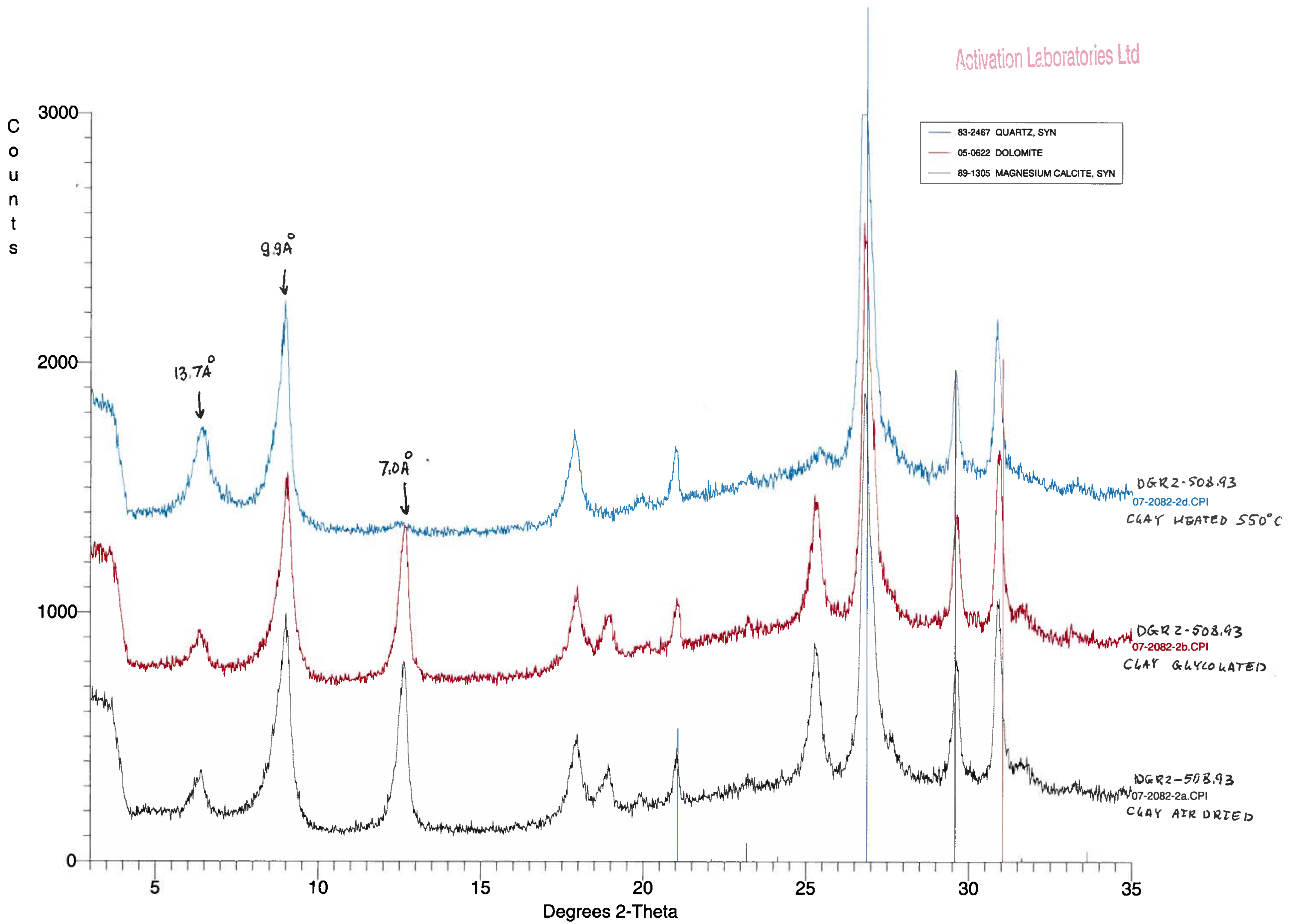
December 13, 2007



December 13, 2007

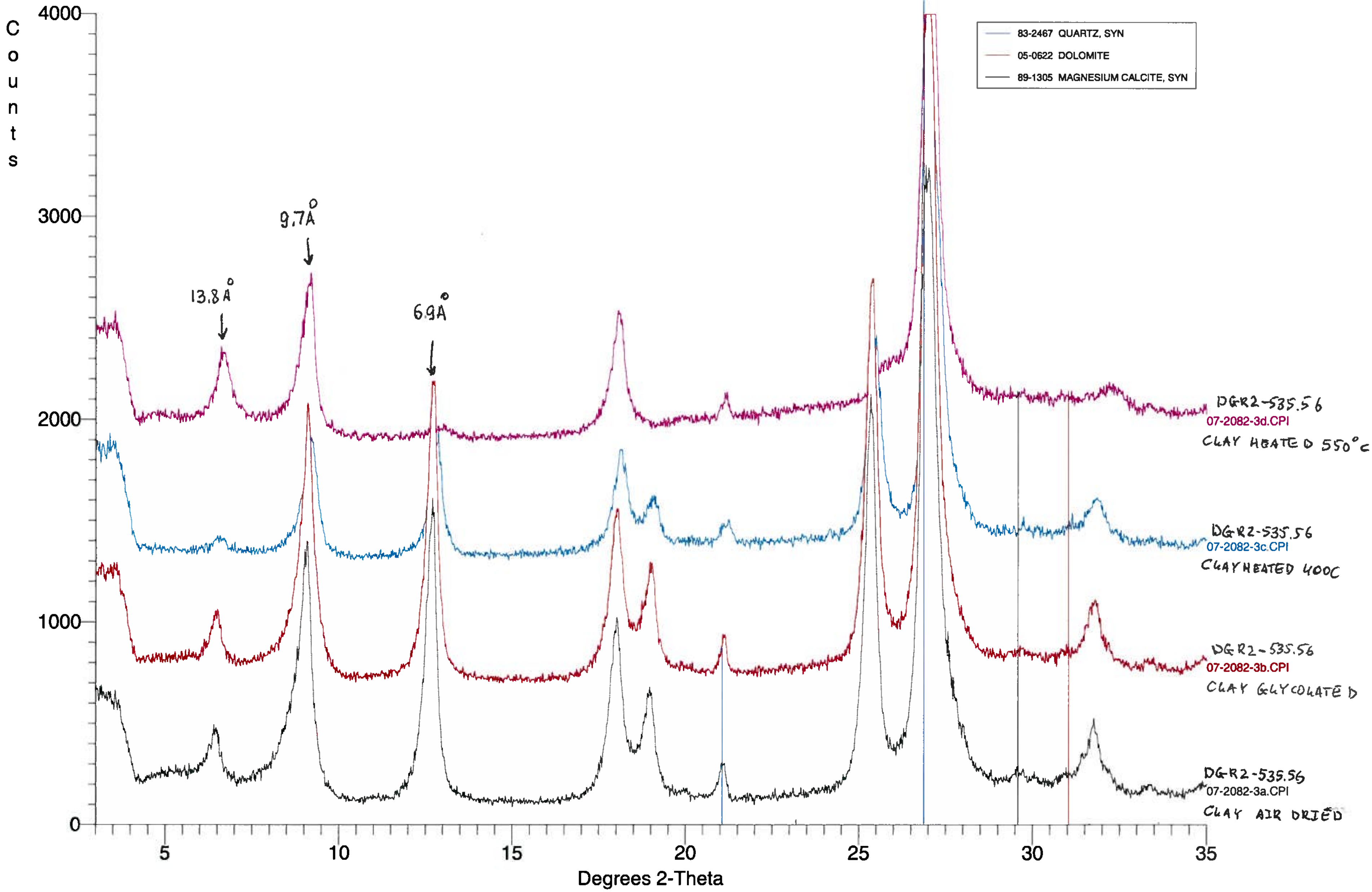


December 14, 2007

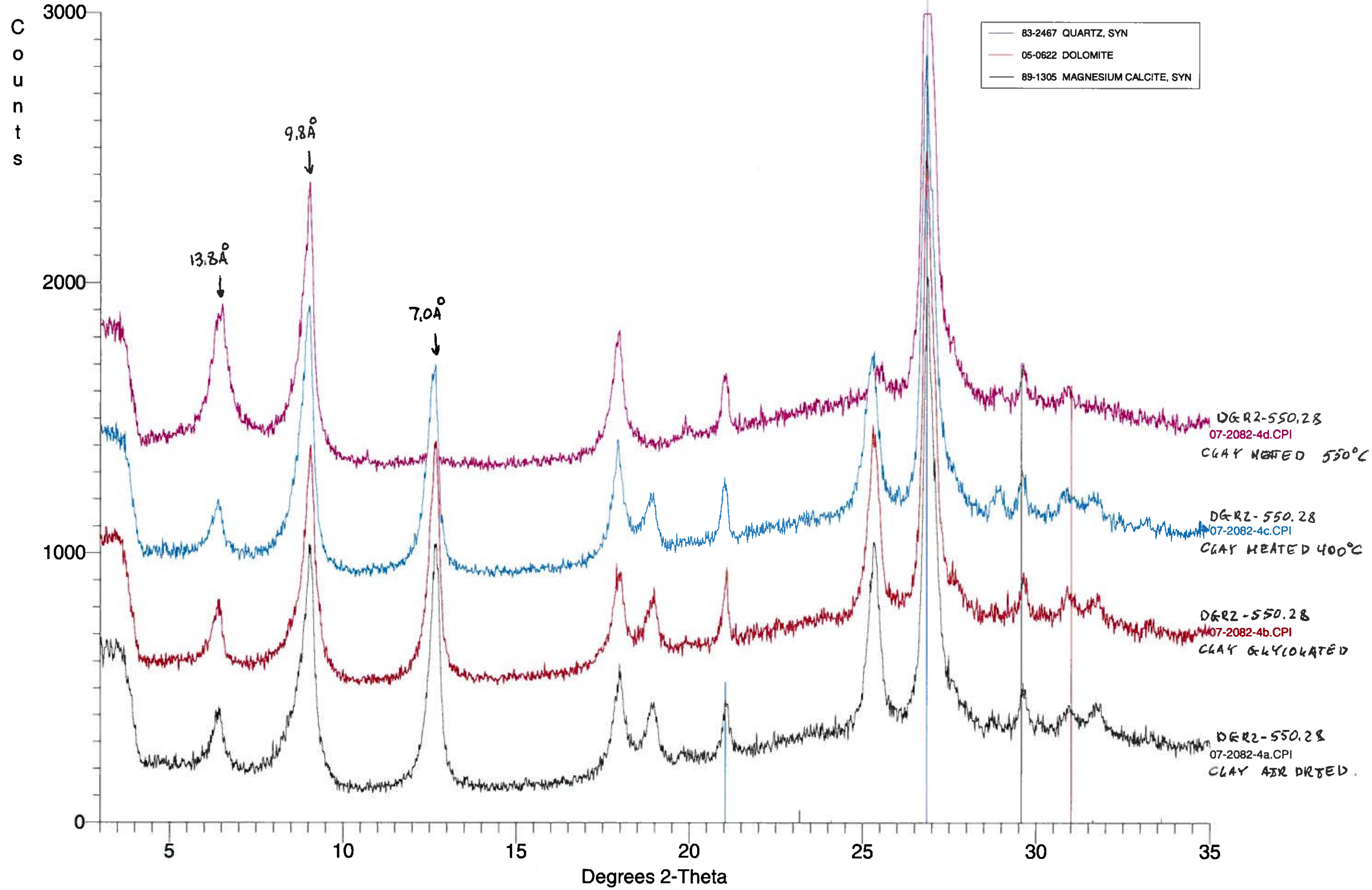


December 14, 2007

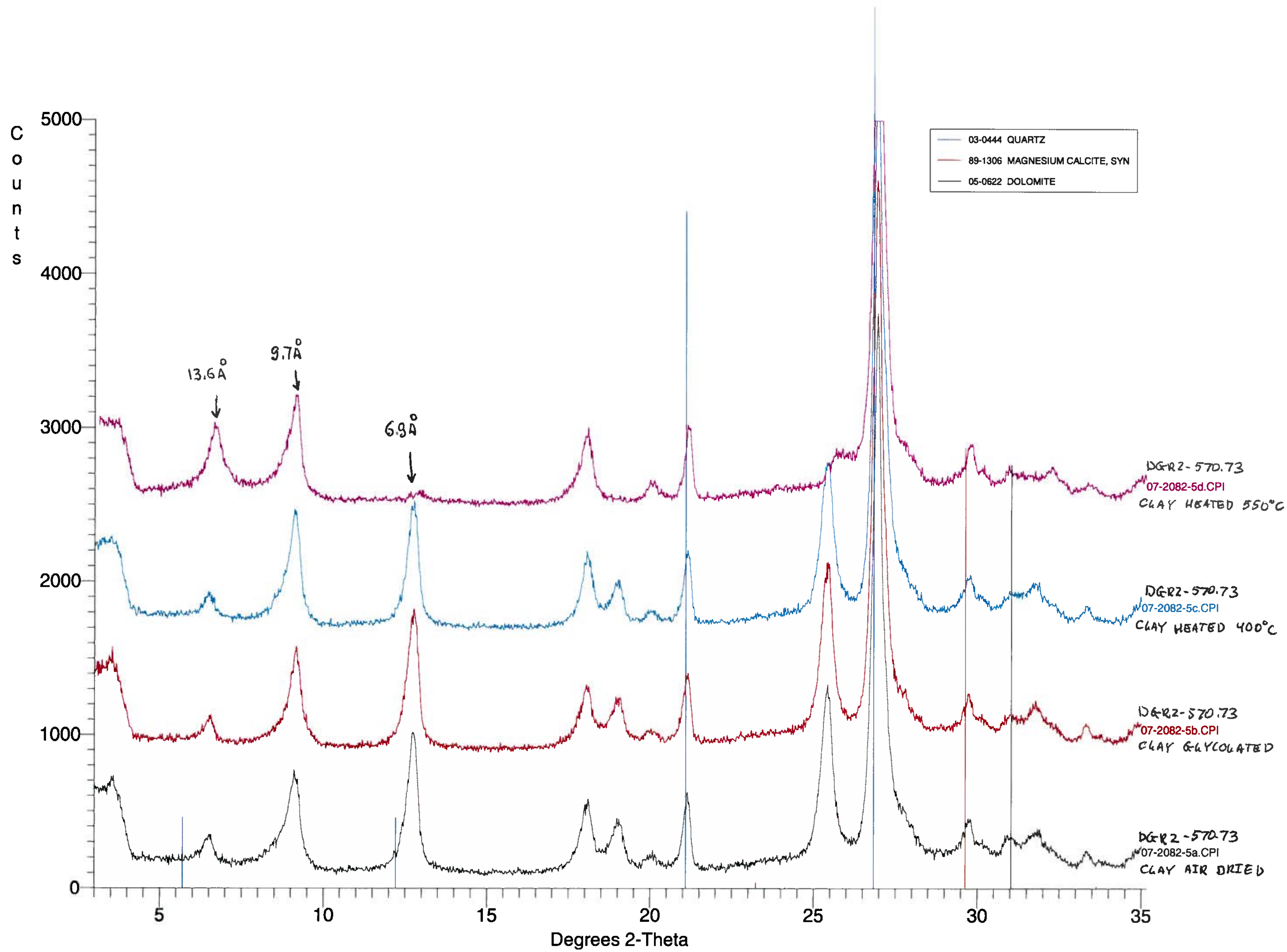
Activation Laboratories Ltd



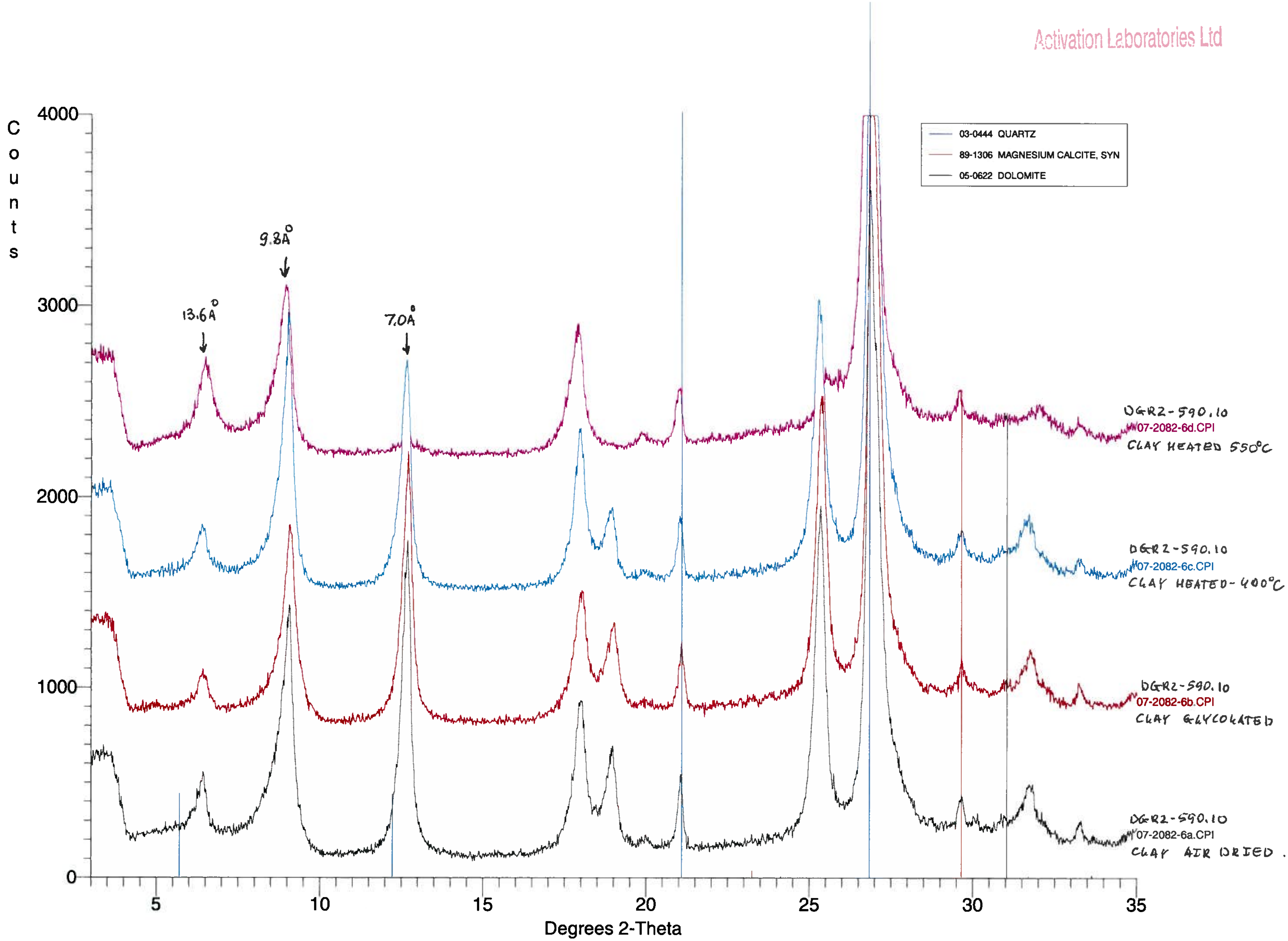
December 14, 2007.



December 14, 2007

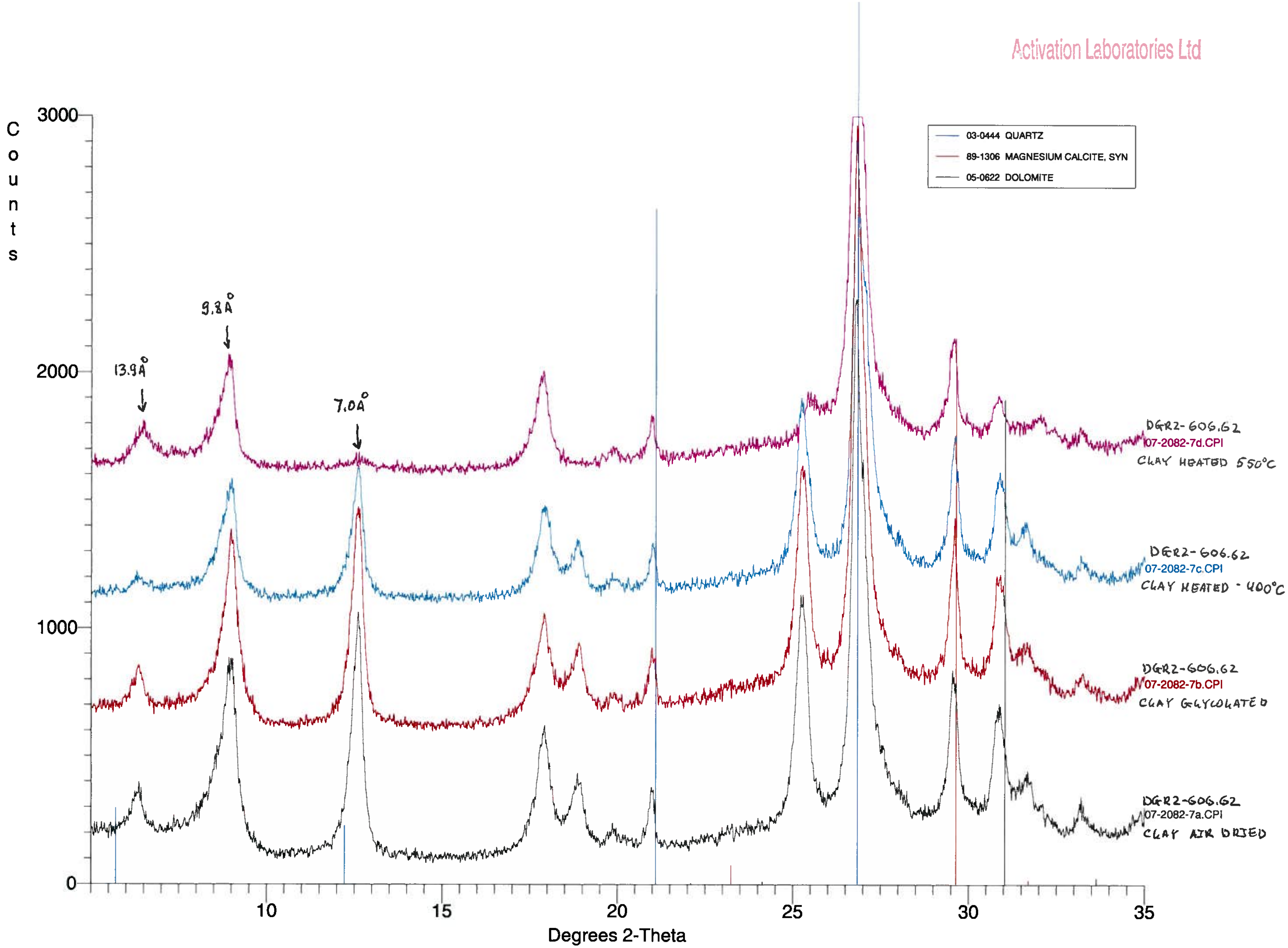


December 14, 2007

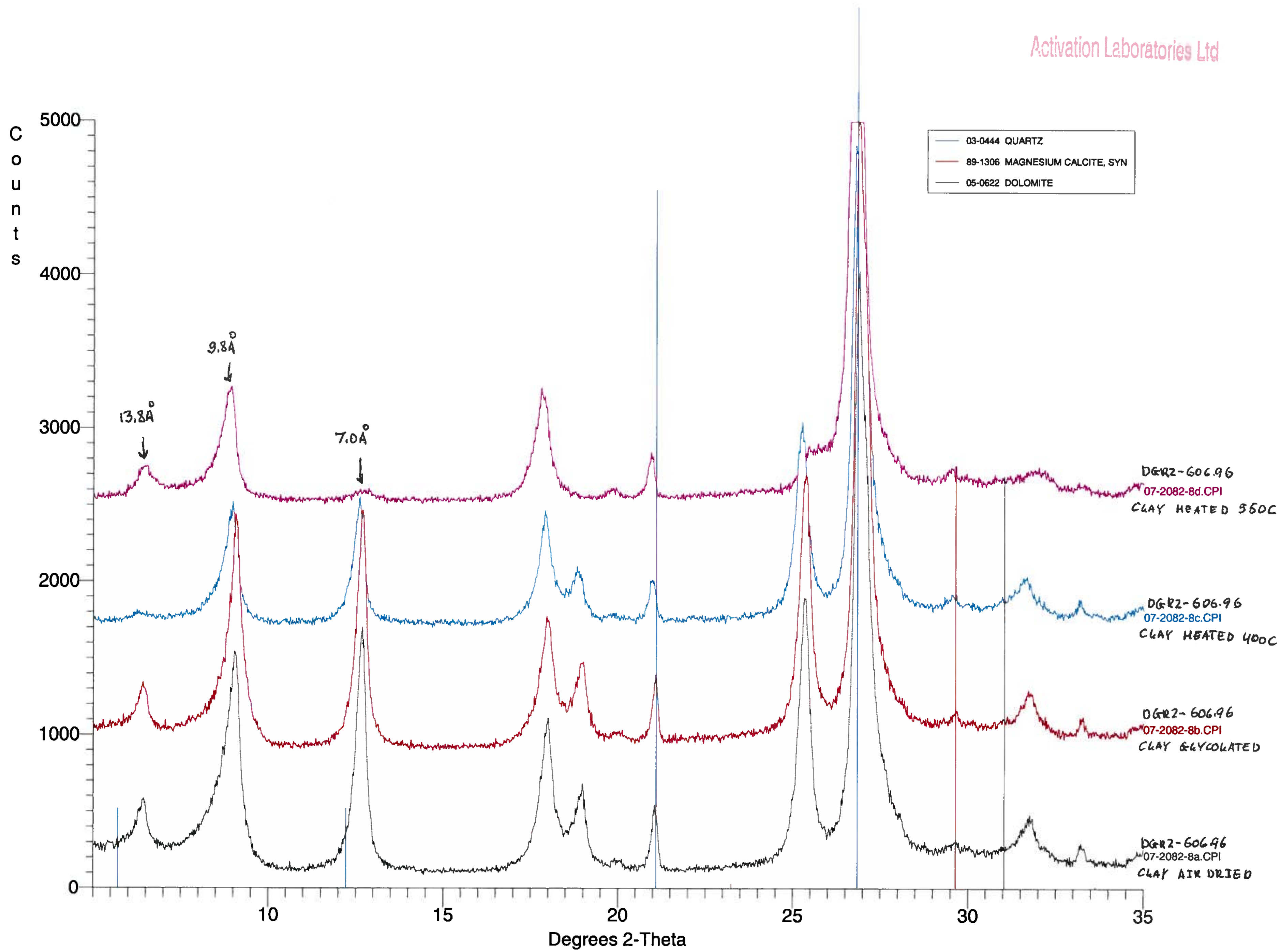


December 14, 2007

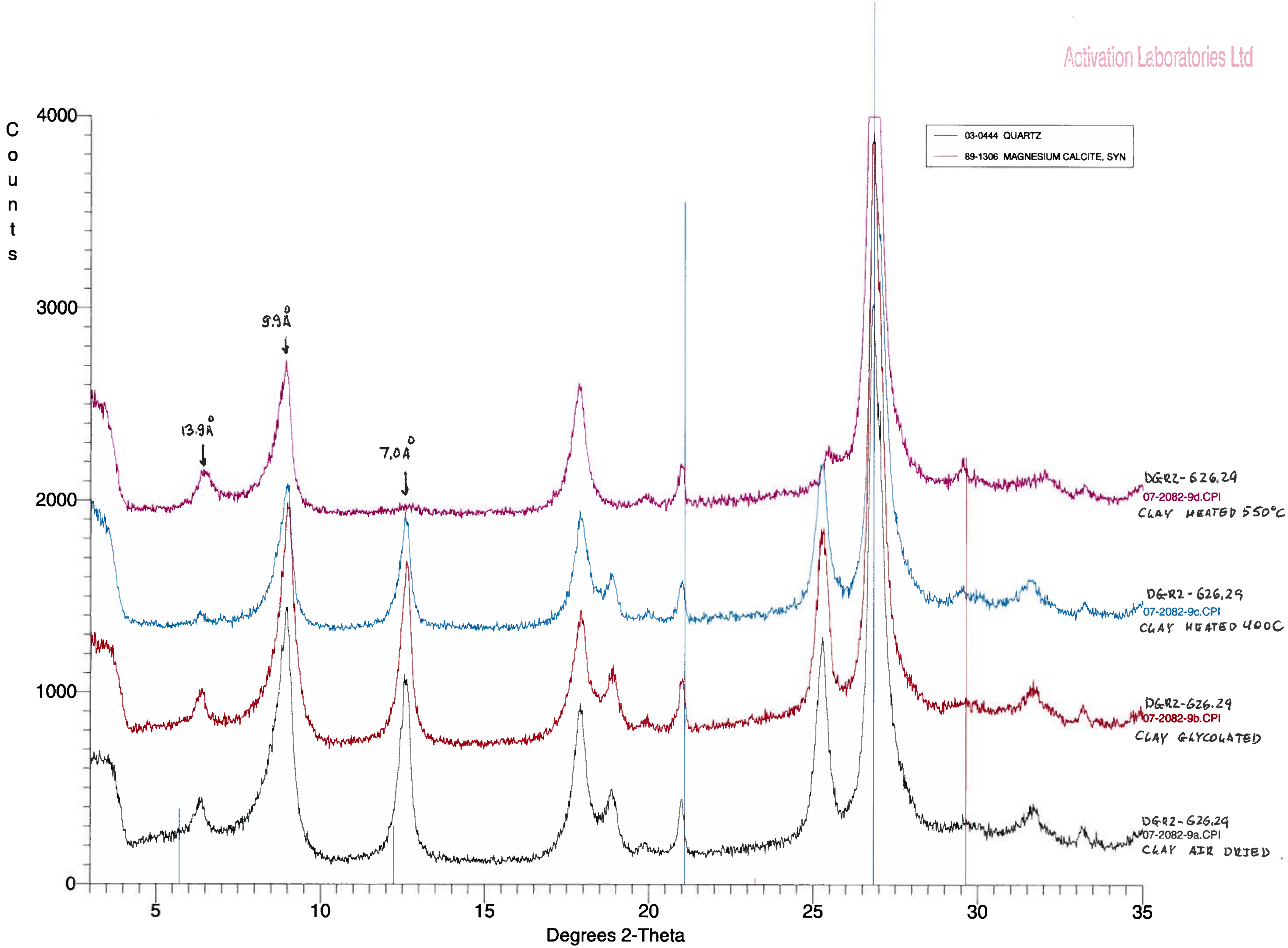
Activation Laboratories Ltd



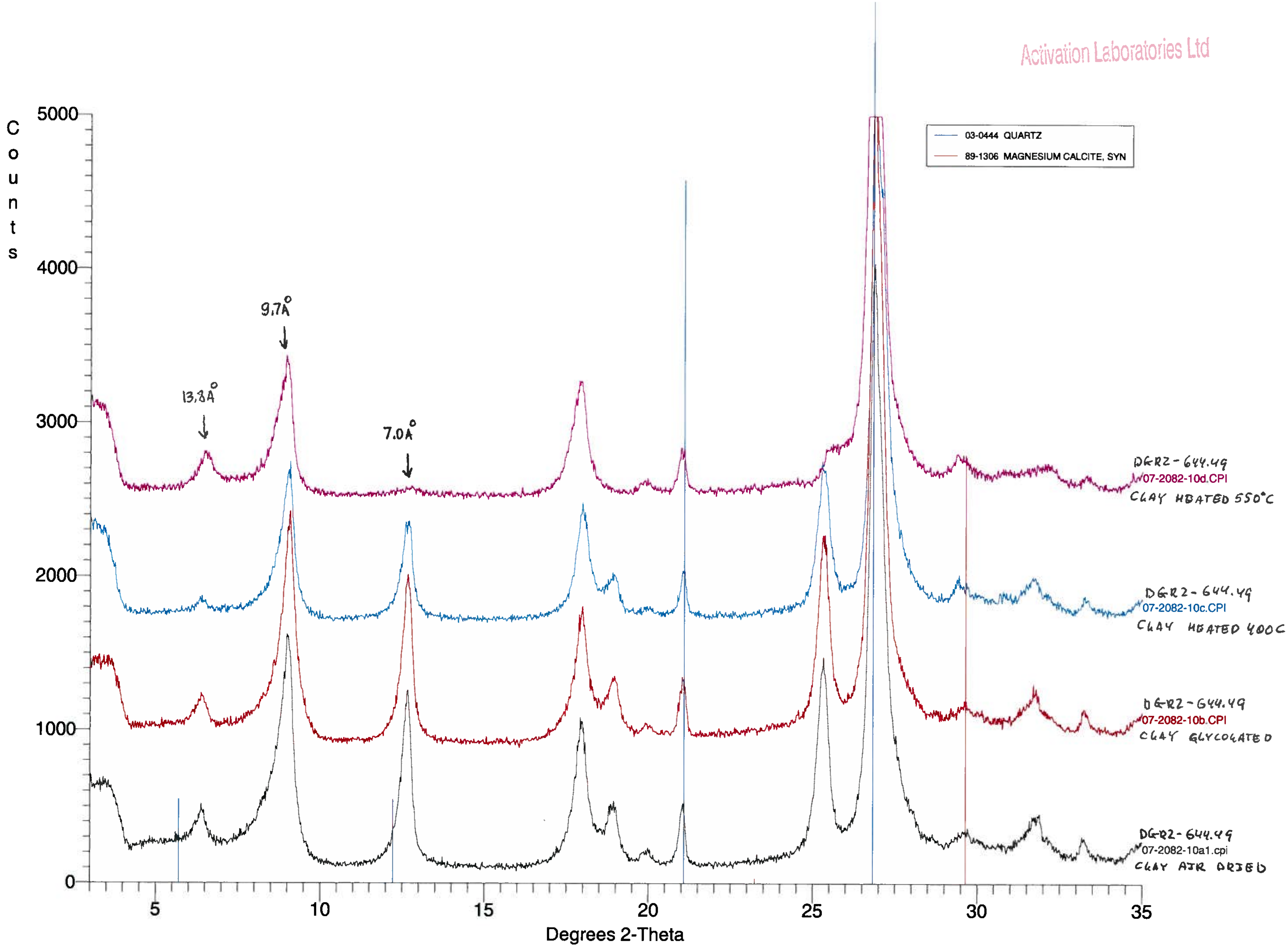
December 14, 2007.



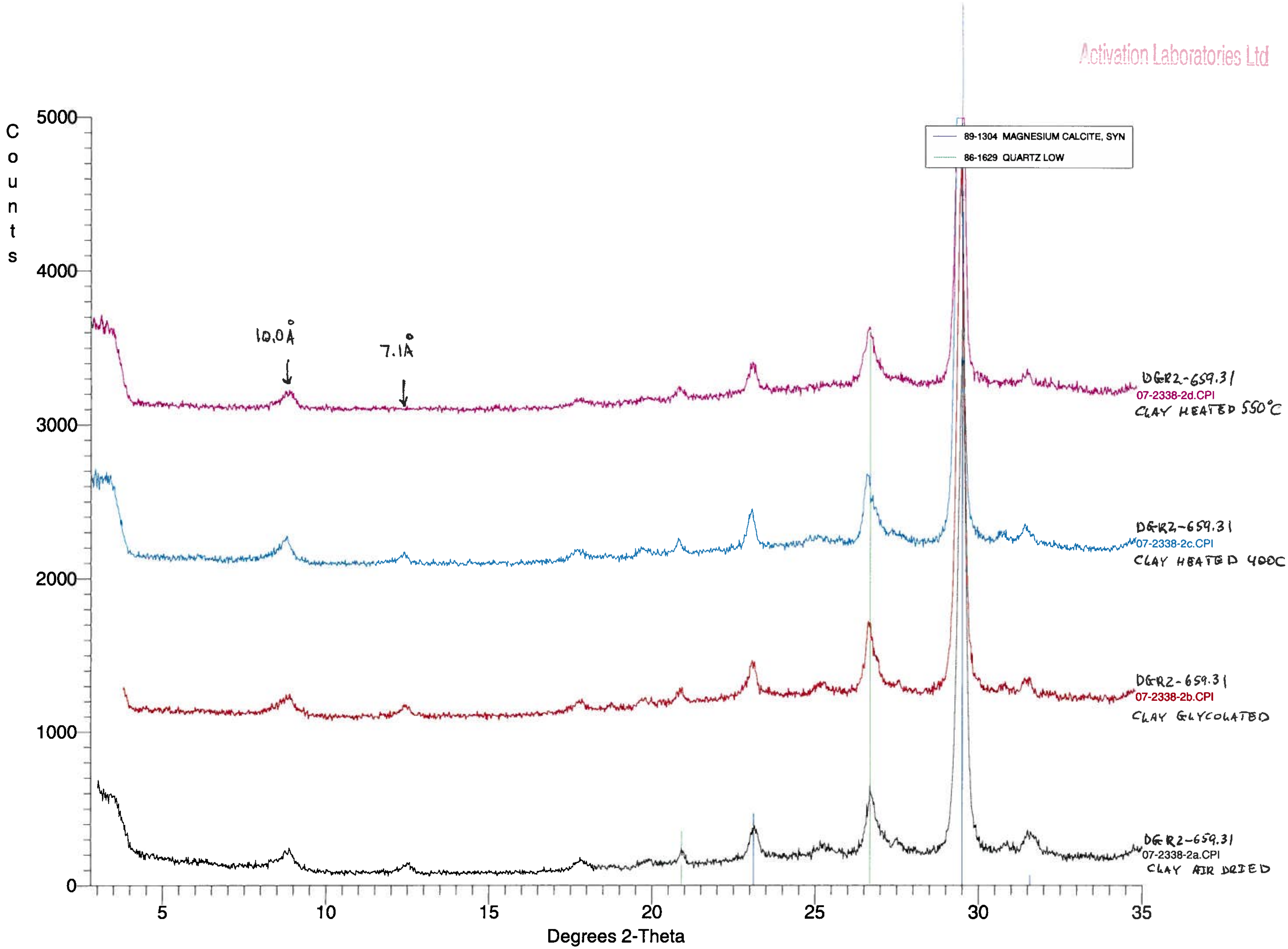
December 14, 2007



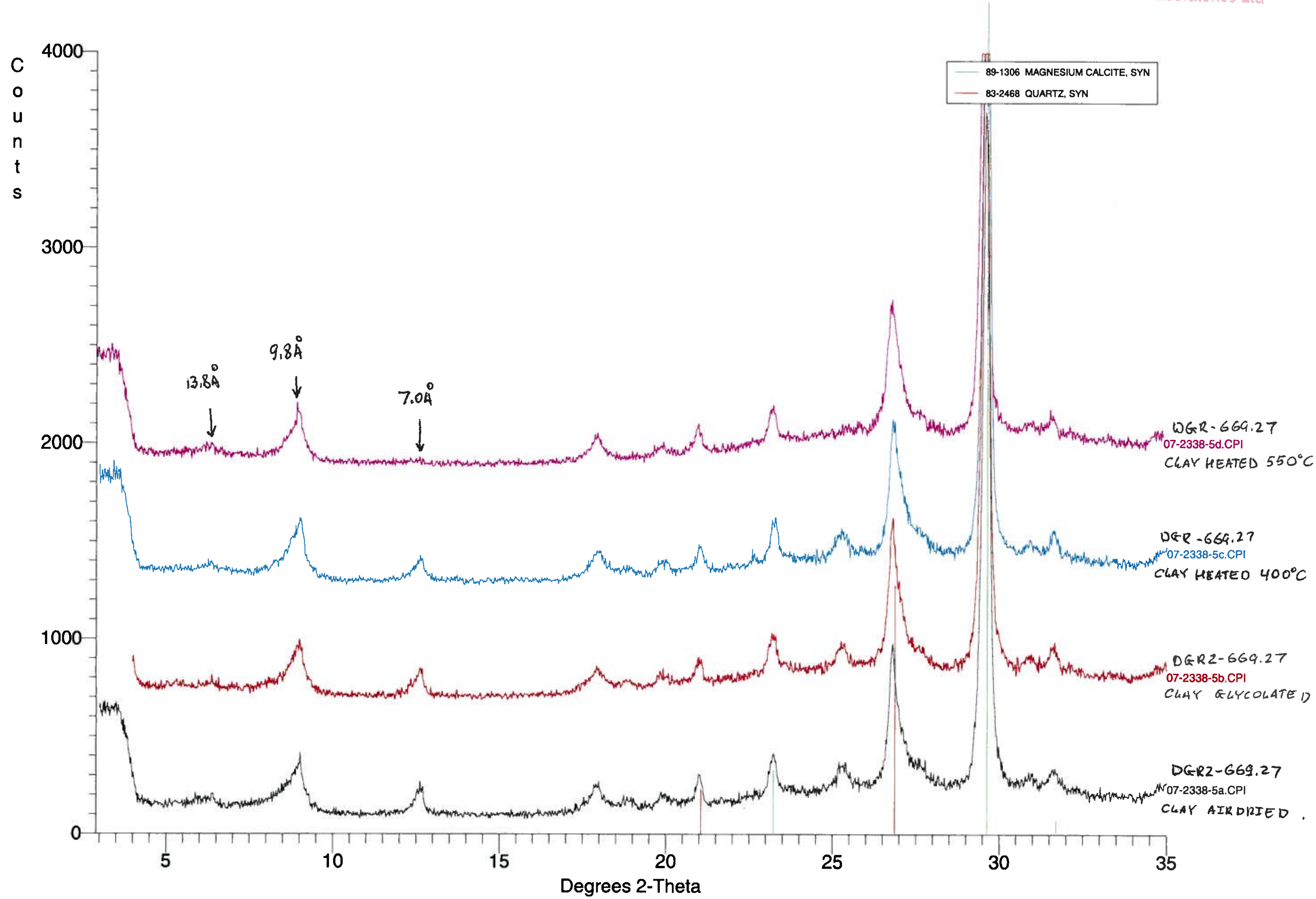
December 14, 2007



December 14, 2007

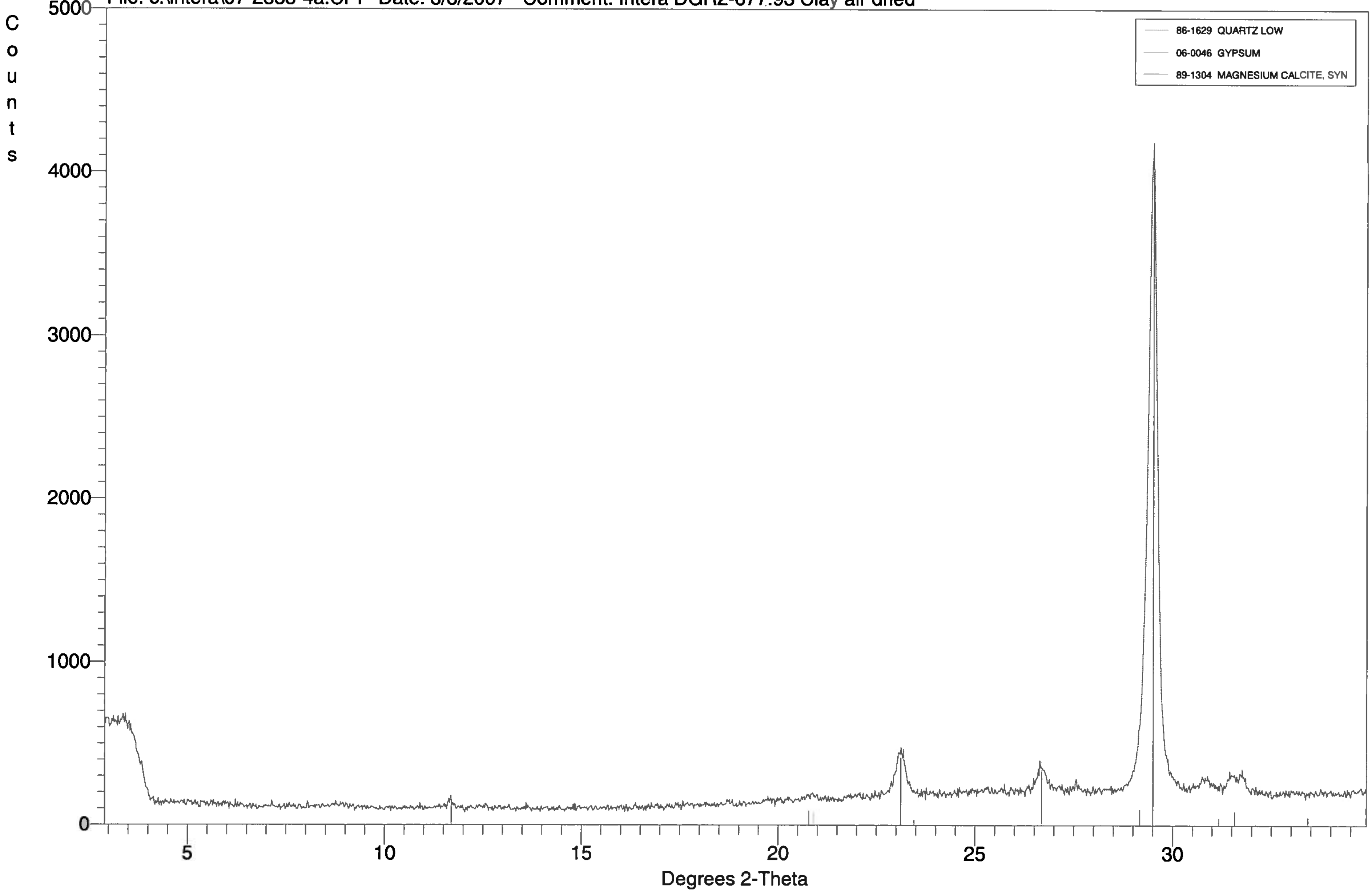


December 13, 2007

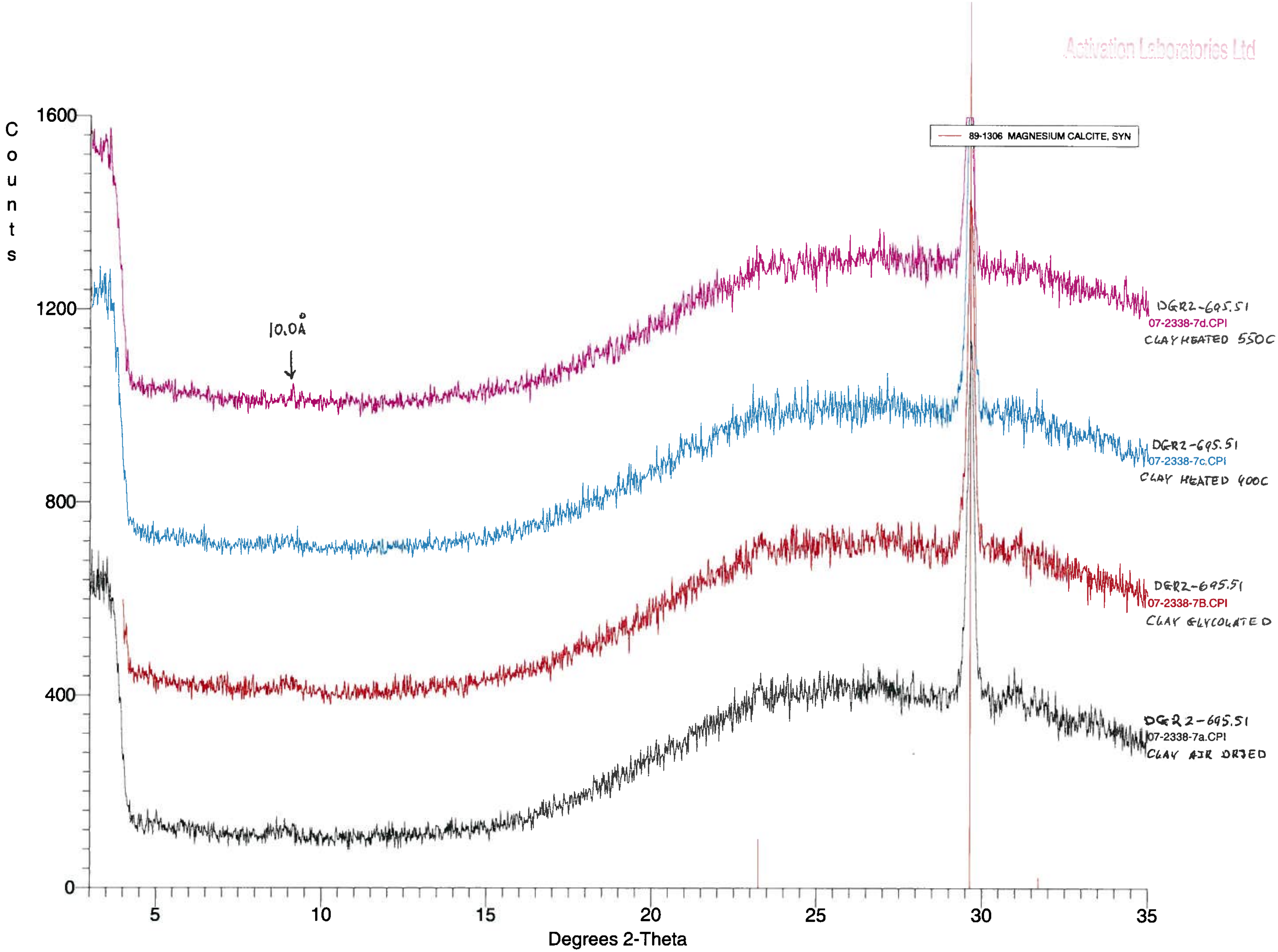


December 14, 2007

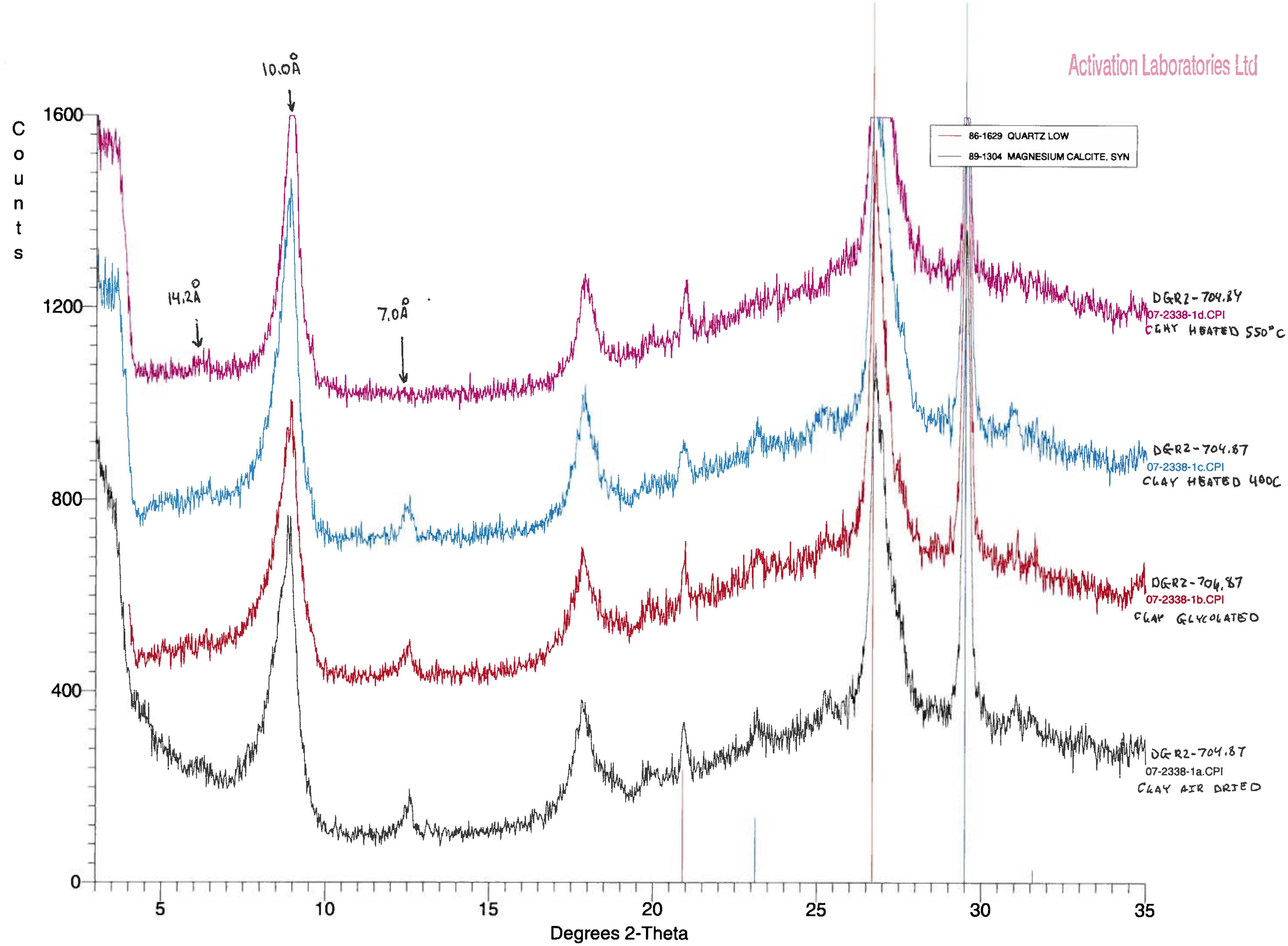
File: c:\intera\07-2338-4a.CPI Date: 8/8/2007 Comment: Intera DGR2-677.93 Clay air dried



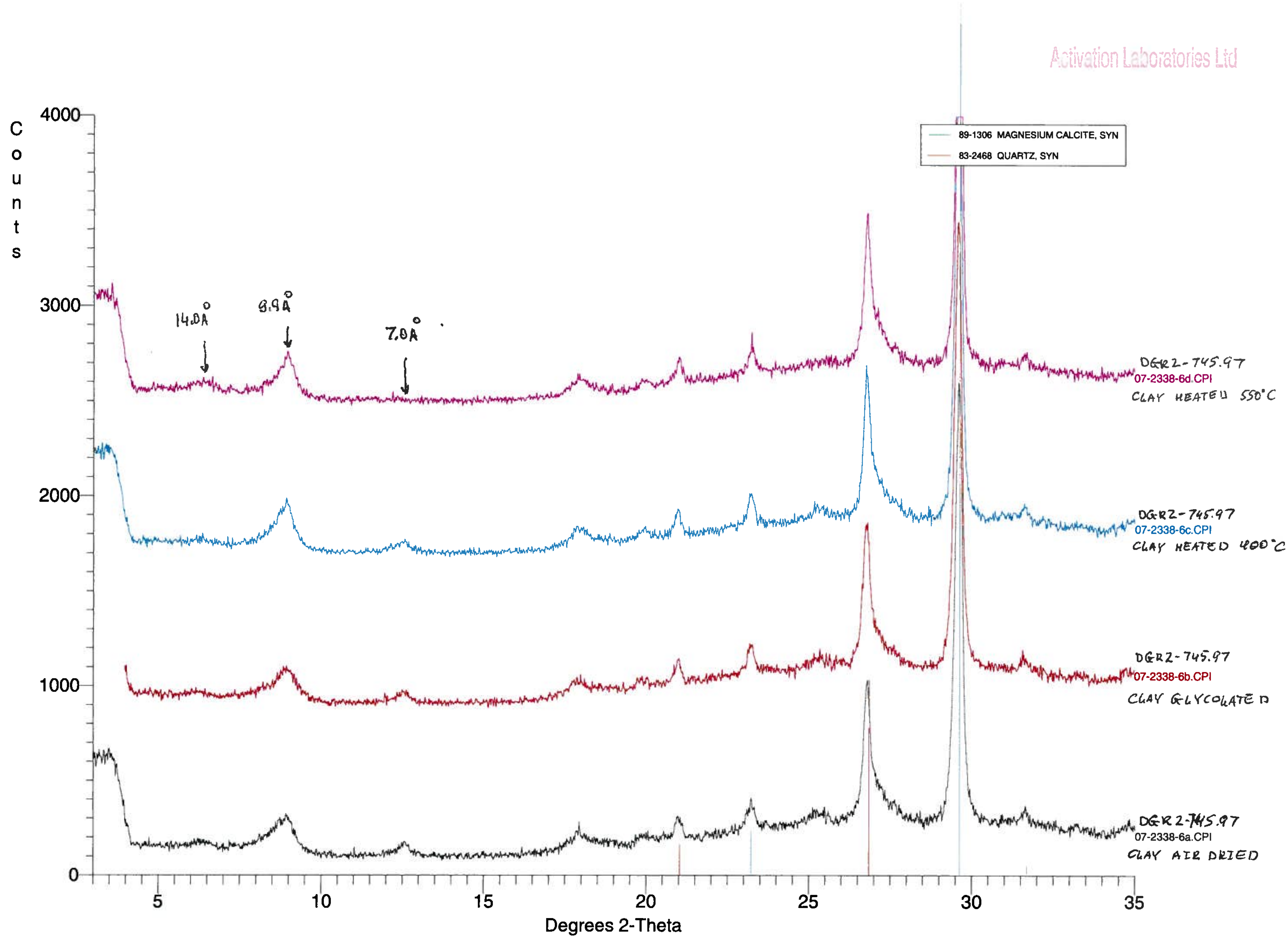
December 14, 2007



December 14, 2007

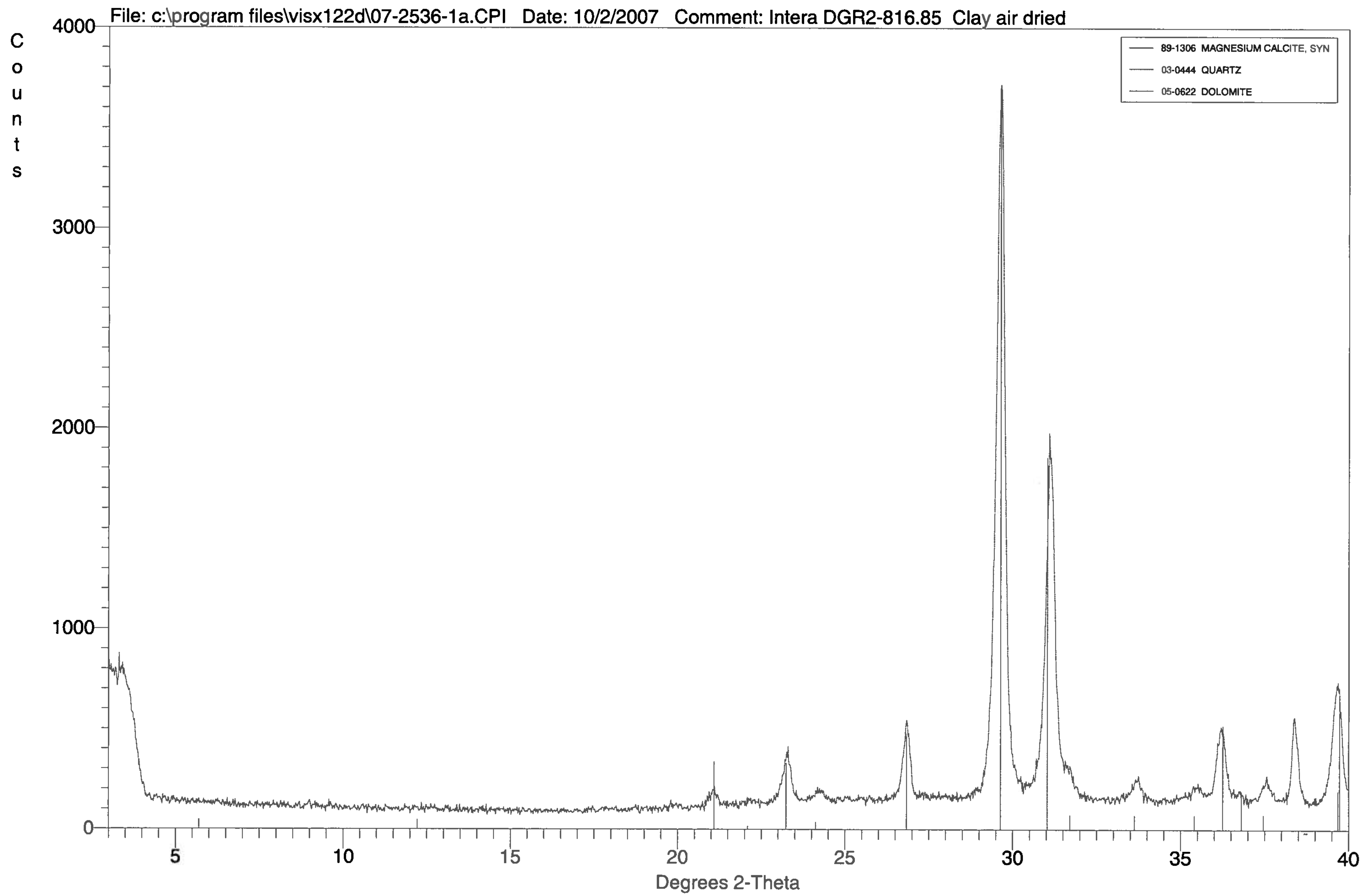


December 13, 2007

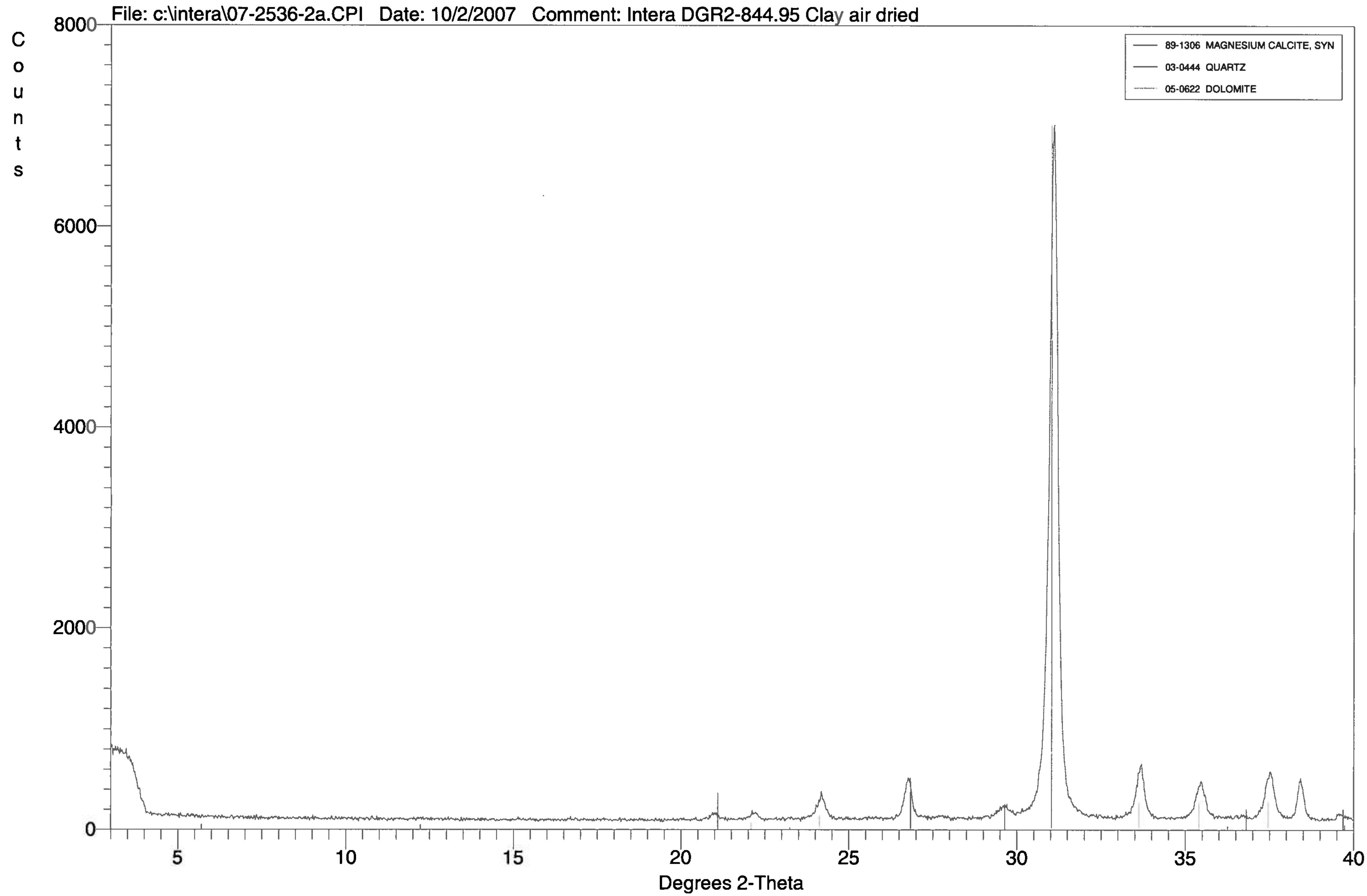


December 14, 2007

Activation Laboratories Ltd



December 14, 2007



December 14, 2007