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Mineralogical Study of Boreholes B98-13 and B98-12 Frontier Hard Chrome Site Vancouver, Washington

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A. Laboratory Report for X-ray Diffraction Analysis	37 pages
B. Laboratory Report for Scanning Electron Microscope/Probe Microanalysis	66 pages

ABSTRACT

The mobility of chromium in ground water is an important consideration for evaluating remedial options for the Frontier Hard Chrome industrial site, Vancouver, Washington. One factor in assessing metal mobility is the degree of chromium reduction and secondary mineralization in a silt unit and underlying sand and gravel aquifer that extends from the site toward the Columbia River. Samples of fill at 16 feet, silt at 21-22 feet, and the underlying aquifer material at 25-26 feet in boreholes B98-13 and B98-12 were collected for chemical and mineralogical analysis. Samples were analyzed by ICP-AES for metals concentration, scanning electron microscopy/electron microprobe for mineralogical texture and microanalysis, powder x-ray diffraction for mineral identification, and optical microscopy for textural observations.

Microprobe analysis showed that chromium occurred in metallic particles originating in the fill material, in iron and iron-titanium oxides that are part of the sediments that were transported by natural fluvial processes through the Columbia River Basin, and in fine-grained iron aluminum silicates that were found in fine sand- to clay-size fractions of both the Silt and Aquifer Units. X-ray diffraction analysis showed that the fine-grained fraction of these units contained an abundant suite of detrital clay minerals including primarily illite, chlorite, and smectite, and lesser kaolinite. The presence of chlorite and smectite is consistent with the microprobe observation of iron-bearing aluminum silicates in the fine grained fraction of the samples. Chromium concentration in the fine-grained material was elevated to a level consistent with chromium in the bulk material and about 10-20 times nearby background concentrations. Though much higher concentrations are found in the metallic particles and iron-titanium oxides, the sparse amount of these phases suggests that an important contributor to the bulk chromium content resides in the clay minerals.

INTRODUCTION

Remedial planning for the Frontier Hard Chrome site in Vancouver, Washington, requires an understanding of the geochemical processes affecting the fate of chromium in the subsurface. Disposal of chrome-plating liquids has left an area of ground water contamination underlying about 30 acres of industrial land along the north shore of the Columbia River. After years of little apparent extension of a concentrated ground water plume of chromium, interest developed in acquiring a more detailed understanding of the nature of chromium mobility at the site. The objective of this study is to identify metal-bearing phases in the Fill, Silt and Aquifer Units. The emphasis is on chromium compounds as well as other minerals that might provide reactive material for enhancing chromium reduction and precipitation of secondary phases. The goal is to determine if there is evidence for the occurrence of natural attenuation at the site.

Some of the terms used here may warrant clarification. The term "minerals", by strict definition, refers to naturally occurring compounds. Although man-made compounds such as some waste materials found in fill are not natural minerals, they are described here by their mineral analog in cases where compound identification can be analytically matched to a unique mineral composition and structure. "Phase" is used here in the general sense for a particular composition of mineral or other compound regardless if naturally occurring or man-made.

Primary minerals or phases are those believed to be an original part of the solid matrix. Secondary minerals or phases are those believed to have formed as coatings or void fillings after formation of the solid matrix, or as in-situ alteration products of primary phases.

METHODS AND MATERIALS

Study Design

Samples were collected from the Fill, Silt, and Aquifer Units in two boreholes located downgradient from the source of chrome-plating wastes, the property formerly housing the Frontier Hard Chrome facility. A sampling and analysis plan for the study was prepared by Roy F. Weston (1998). The samples were analyzed for metals concentration by ICP-AES, and for mineralogy by scanning electron microscopy/electron microprobe (SEM/EPMA), x-ray diffraction (XRD), and low-power optical microscopy. A sample preparation procedure was used to separate grain sizes as a means of concentrating mineral phases associated with particular size ranges. The separation procedure was expected to potentially concentrate more reactive material, and possibly secondary minerals, in the smaller size fractions. Accordingly, a fine-grained separate was prepared to provide a concentrate of secondary minerals. The coarser-grained separates, on the other hand, provided larger-sized material expected to have intact coatings or alteration rims made up of relatively harder secondary minerals.

Field Work

Samples were collected with a 2.5 inch inside-diameter split-spoon sampler driven through an 8-inch hollow-stem auger (Roy F. Weston, 1999). On April 27, 1998, six samples for chemical and mineralogical analysis were collected from boreholes B98-13 and B98-12, located 100-200 feet southeast of the Frontier Hard Chrome building and approximately 3000 ft north of the Columbia River (Figure 1). Seven additional samples were collected from boreholes B98-20A and B98-21A on April 30 and B98-21B on May 28, approximately 900 feet south and downgradient of B98-12 and B98-13 (Figure 1). These later samples were submitted for chemical analysis and archived for possible mineralogical analysis pending review of the chemical data. Mineralogical analysis of the distal samples was not conducted because of their low chromium content.

For the samples that underwent mineralogical analysis, Table 1 lists the sample numbers, depths, and unit descriptions from the field report (Roy F. Weston, 1999). Three units were sampled in each of the two boreholes. The units include fill at a depth of 16 feet, silt at 21-22 feet, and the Aquifer A-zone at 25-26 feet. In order to provide information on variability within a sampled unit, two portions of the sample from the Silt Unit (SBR1-9813-0210) from borehole B98-13 were prepared for analysis. Therefore a total of six field samples and one duplicate were carried through the mineralogical procedures.

Laboratory Methods

Approximately 500 g of each sample were separated by wet sieving to produce five size fractions: gravel (>2 mm), coarse sand (0.5-2 mm), fine sand (0.07-0.5 mm), and silt and clay (<0.07 mm). The gravel fraction was further divided at about 10 mm into larger gravel and smaller gravel. No gravel fragments were larger than about 20 mm. Each size-separate was assigned a new lab number for a total of 35 laboratory samples generated from the original six field samples and one duplicate (Table 1).

The size separates were well mixed and split for optical microscopy and x-ray diffraction analysis at the Manchester Laboratory, and for scanning electron microscopy/electron probe microanalysis at Cannon Microprobe, Seattle. The larger gravel clasts (>10 mm) were split with a diamond saw. The remaining sand and gravel fractions were split with a riffle splitter, and the silt and clay fractions were split by quartering. Table 1 lists the percent weights resulting from the size separation.

X-ray diffraction analysis was accomplished at the Manchester Laboratory with a Scintag X1 powder diffractometer using $\text{CoK}\alpha$ radiation at a wavelength of 1.78897 angstroms (\AA), generated at 36 ma and 45 kv. Several diffractograms were also acquired early in the project with $\text{CuK}\alpha$ radiation at 1.54056 \AA at 40 ma and 45 kv. Diffractograms were recorded at scan speeds of 15 degrees and 0.5-1 degrees of two-theta ($^{\circ}2\theta$) units per minute over a 2-76 degree range. The XRD method provided qualitative identification of minerals greater than about five percent in concentration. Identifications were made by matching measured diffraction patterns with a database maintained by the International Centre for Diffraction Data (1996), and by comparison with the literature as noted. Clay mineral identifications were verified by chemical and thermal treatments that alter the structural thickness of clay minerals in a diagnostic manner as described by Brindley and Brown (1980) and Moore and Reynolds (1986). The clay minerals were expanded by intercalation with ethylene glycol, and contracted by heating at 150°, 300°, and 550° C.

A Frantz LB-1 magnetic barrier separator was used for selected samples to provide mineral concentrates for both XRD and microprobe analysis. Additional separation of the finest fractions was accomplished by vacuum filtration of re-suspended particulates in deionized water onto 0.45 μm cellulose filters. A Wild M5-A stereomicroscope was used for optical microscopy with incident light in order to describe and document samples and XRD specimens. The XRD laboratory report is in Appendix A and contains a list of analyzed separates, matched phases, annotated diffractograms, and notes on microscopic observations.

Scanning electron microscopy/electron microprobe analysis was performed at Cannon Microprobe, Seattle, using an ARL SEMQ electron microprobe at 20 kv and 50 na beam current. Both grain mounts and polished sections were prepared as specimens. Scanning electron microscope images were made in the backscattered electron detection mode (BSE images) by which image contrast is a function of atomic number. Microanalysis was accomplished with the probe using a Kevex energy-dispersive x-ray spectrometer (EDS) for rapid detection of several elements, and four wavelength-dispersive x-ray spectrometers (WDS) for quantitation of

chromium, manganese, barium, and iron. The WDS analytical volume is about one cubic micrometer. The microprobe report is in Appendix B and contains a narrative discussion of the distribution of chromium, lists of WDS analyses for four elements, a group of BSE images, x-ray map images for chromium and manganese, and a group of EDS spectra.

RESULTS

The borehole samples consist of granular material that spans a size range from clay to pebbles (Table 1). The Fill Unit has the coarsest material, and the Silt Unit has the finest. Samples from the Fill Unit have primarily dark gray to black sand and gravel with about 14-19% fines of silt and clay. Samples from the Silt Unit have dark gray to dark grayish brown silt and clay with 61-67% fines. Samples from the Aquifer Unit have dark brown to dark grayish brown sand and gravel with 23-27% fines.

Visual examination of the gravel fractions indicate the most common rock types in these samples are black basalt, gray andesite, and white to beige quartz and quartz-rich rocks such as quartzite and granodiorite. The Fill Units from both boreholes contained calcite-coated pebbles from chunks of concrete. The Fill also has a large proportion of angular basalt, suggestive of crushed aggregate. Many of the basalt pebbles in the Fill Unit are coated with asphalt. The Silt and Aquifer Units have a much smaller proportion of angular pebbles than the Fill Unit, though angular basalt fragments are still common in the coarse part of the Silt Unit.

Results of the chemical analyses of borehole samples are listed in Table 2. Included with the results for boreholes B98-13 and B98-12 are the more distal samples from B98-21A, B98-21B, and B98-20 (Figure 1). Table 2 shows that chromium concentrations are highest in B98-13 and B98-12 for all Units. Within each borehole, chromium is relatively higher in the Silt Unit and is also preferentially concentrated in the silt and clay fractions of the Fill and Aquifer Units. Other metals that had highest concentrations in boreholes B98-13 and B98-12 include iron, sodium, calcium, potassium, copper, lead, and zinc.

Distribution of Minerals

Table 3 lists the phases discussed in this report and appendices, including the mineral name, ideal chemical formula, and whether the phase is found by XRD or microprobe analysis. Tables 4 and 5 provide a summary of the XRD and microprobe results, respectively.

With reference to the XRD results in Table 4, the common rock-forming minerals, quartz and feldspar are ubiquitous, occurring as major minerals in all of the samples. Mica and the clay minerals are abundant as minor components in both the Silt and Aquifer Units. From the size distribution (Table 1), the Silt Unit contains over 60% silt- and clay-size grains for which XRD indicates the presence of abundant clay minerals. Prominent among the clay minerals are those that are potentially iron-bearing, chlorite, smectite, and illite. Lesser kaolinite also occurs in the Silt Unit. The Aquifer Unit contains a similar group of clay minerals, but in somewhat less amount than the Silt Unit.

A distinctive feature of the clay minerals is a lack of interstratification. Reaction among clay minerals to form mixed layer clays, or interstratification, is a common occurrence in active soil-forming environments. Lack of interstratification indicates that the clay minerals are detrital rather than authigenic. In other words, these clay minerals probably do not represent secondary mineralization at the site, but rather were transported into the area by fluvial processes.

XRD examination of coatings found calcite coatings to be common. The Fill Unit contains major calcite and trace aragonite and vaterite in coatings associated with remnants of concrete. Vaterite was also detected in coatings in the Silt Unit suggesting that this unit has entrained concrete fragments in the area of Borehole B98-13. The Fill Unit at both boreholes also contains abundant asphalt covered pebbles of angular basalt.

In general, coatings other than calcite or asphalt are not at all common in the borehole samples. Orange and yellow-stained grains occur, but the stains are very thin and did not provide enough mass for identification of a discrete phase by microprobe. A group of such grains was examined by XRD and found to contain chlorite (Table 4-sand and gravel fraction). The association of chlorite with an orange coating suggests that the chlorite is an iron-bearing variety.

No discrete chromium- or manganese-bearing phases were found by XRD, indicating that any such minerals are less than 5% in concentration. Of the minerals identified by XRD, those most likely to provide reactive sites for chromium are the clay minerals which tend to incorporate iron, particularly chlorite and smectite.

With reference to the microprobe results summarized in Table 5, the phases with the highest chromium content are rare grains of chromite, iron-titanium oxides, spinel, and iron metal. Figure 2 shows backscattered electron (BSE) images of representative textures of these phases in the Silt Unit. Chromite (Figure 2A, grain with about 57% chromium), and iron-titanium oxides and spinel (Figure 2B, zoned grain with up to 15% chromium) may be naturally occurring as they would be consistent with the abundant basaltic content of the borehole material. Iron metal (Figure 2C, 4.6% chromium) is probably associated with the man-made fill material. Chromium-bearing metallic grains were identified not just in the Fill Unit, but also in the Silt and Aquifer Units (Table 5).

The microprobe data show that some of the metallic grains which have high chromium content are depleted of chromium around their edges, indicating the grains underwent leaching. For example, an x-ray map of chromium distribution in a grain of metallic iron (image X-1 in Appendix B) from the Fill Unit shows decreased chromium in the corroded rim of the grain. Similarly, some grains of chromium-bearing metallic iron were also found to have iron oxide or iron aluminum silicate crusts which were depleted of chromium (Figure 2C), indicating either the occurrence of leaching or at a lack of secondary chromium mineralization.

In contrast to the rare chromium-rich grains, a fine-grained iron-bearing aluminum silicate phase (FeAlSi in Table 5) was identified by microprobe to be the most common chromium-bearing phase, but with relatively lower chromium content (Figure 2D, 0.5% chromium). Inspection of the WDS quantitative results for chromium in the microprobe report

(Appendix B) shows that many of the chromium values for iron-bearing aluminum silicate in the Silt Unit in B98-13 (sample 56) are in the range of 0.05% (500 ppm) or less. Although this amount of chromium is low relative to discrete chromium minerals such as chromite, 500 ppm is still more than ten times a probable natural background for the Vancouver area. The average chromium content of the iron aluminum silicate is difficult to determine from the data; the probe report suggests a value of about 0.15% for the Silt Unit in B98-13 (sample 56). The chromium content of iron aluminum silicate in the Silt Unit in B98-12 (sample 72) appears to be higher than in B98-13 but still less than a percent. The iron aluminum silicate phase is also found in the Aquifer Unit at both boreholes (Table 5). The microprobe report indicates that some of the iron aluminum silicate phase had no detectable chromium at all, indicating concentrations below the reported chromium detection limit of 200-400 ppm by WDS.

DISCUSSION

The distribution and textural characteristics of the iron-bearing aluminum silicate phase identified by microprobe indicate that it is the same material that was identified as clay minerals by XRD. The microprobe results show that the phase is most concentrated in the Silt Unit and the SEM images show it to be very fine grained. XRD data show that corresponding clay minerals are most abundant in the Silt Unit. Although the iron aluminum silicate material is too fine-grained to yield a discrete description by microprobe, XRD provides identification of a unique set of minerals (illite, chlorite, smectite, and kaolinite) with chlorite and smectite the two most likely to have high iron content.

Since the microprobe found a few hundred to a few thousand parts per million chromium in the iron aluminum silicate, the data suggest that iron-bearing chlorite and smectite may be preferentially incorporating chromium. Not only is the concentration of these clay minerals elevated in the Silt Unit relative to the other Units, but also the bulk chromium content of the Silt Unit exceeds that of the other units in each respective borehole (Figure 3). Additionally the silt-size fractions of the coarser units contain elevated chromium relative to the bulk samples (dotted pattern in Figure 3). Therefore both the mineral and chemical distribution demonstrate that chromium is preferentially associated with fines containing the clay minerals, chlorite and smectite.

The mineralogical data do not establish the specific type of interaction between chromium and the clay minerals. For example, chromium-bearing chlorite could occur in which chromium is an essential part of the chlorite structure. Such binding might provide relative long-term immobility for precipitated chromium. Alternatively, chromium could occur as a coprecipitate in the clayey material, an adsorbed phase on a clay mineral surface, or an exchangeable ion. The various types of binding would have different degrees of permanence for immobilizing chromium, depending on reactivity with future ground water composition. Because of detection limits, the chromium concentrations would have to be higher than those found in these boreholes in order to determine the nature of chromium binding by the mineralogical methods used here.

CONCLUSIONS

With respect to the objectives of the study, several chromium-bearing phases have been found and can be placed in three general groups:

1. Metallic materials associated with man-made fill,
2. Chromite, iron and titanium oxides, and other igneous minerals associated with basalts, and
3. Iron-bearing clay minerals.

A second objective was to determine if phases were present that could be expected to react with chromium in an attenuation process. The iron-bearing clay minerals in the Silt and Aquifer Units represent such phases and they are common.

The goal of the study was to determine if there is sufficient evidence for the natural attenuation of chromium. Sufficient evidence is not available from the mineralogical data at hand. Chromium appears to be somewhat concentrated in the clay minerals, which is consistent with an attenuation process. However, the concentrations are not sufficient to determine the nature of the binding or the presence of a discrete chromium-bearing mineral. Therefore the permanence of attenuation under present or future conditions could not be determined.

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Figures

1. Index map of the Frontier Hard Chrome
2. Selection of BSE images
3. Distribution of chromium concentration with depth

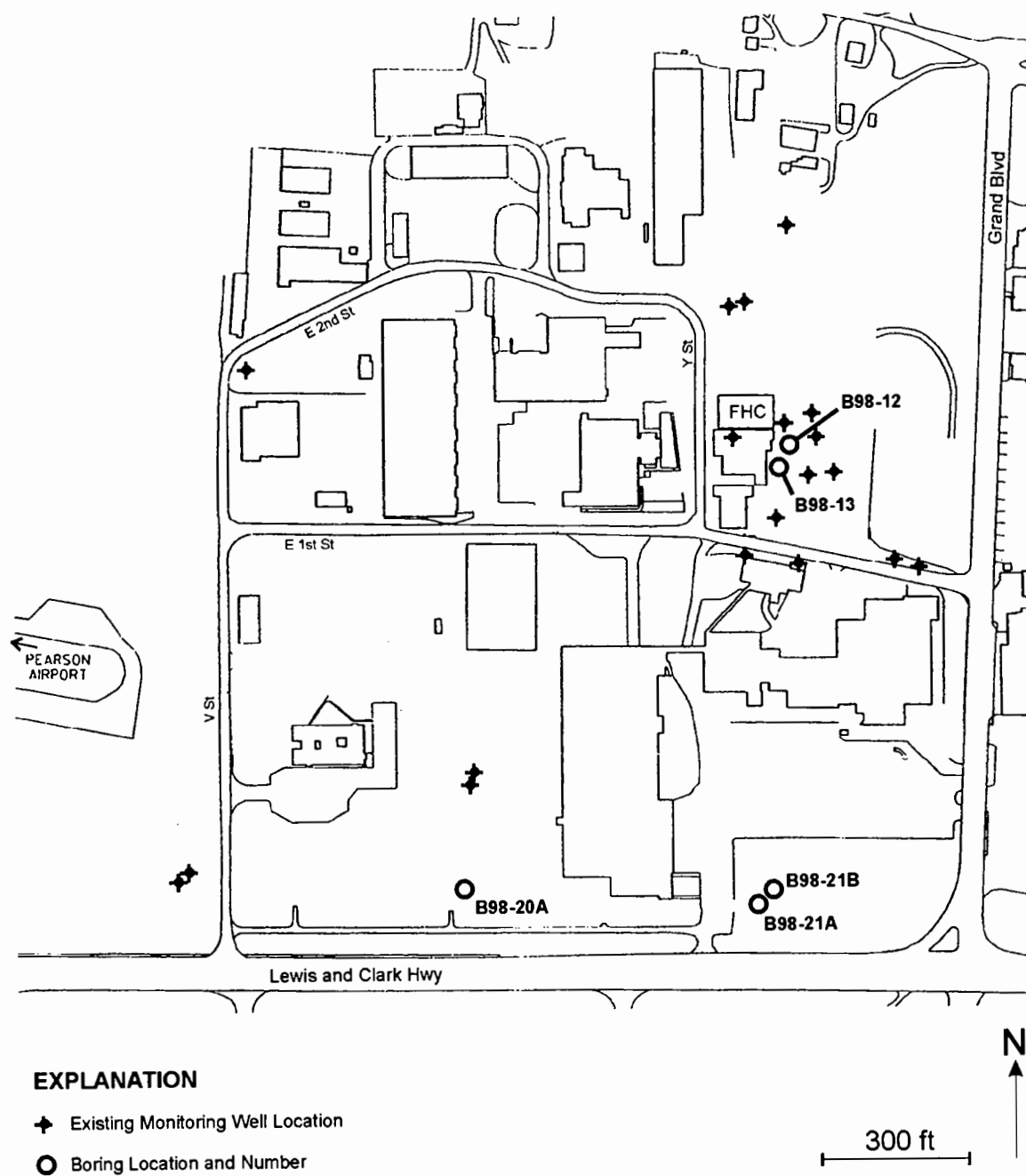


Figure 1. Index map of the vicinity of the former Frontier Hard Chrome building (FHC) and nearby boreholes. Samples from B98-13 and B98-12 underwent mineralogical analysis. Map is modified from Roy F. Weston (1999); newer roads along the south border of map are not shown.

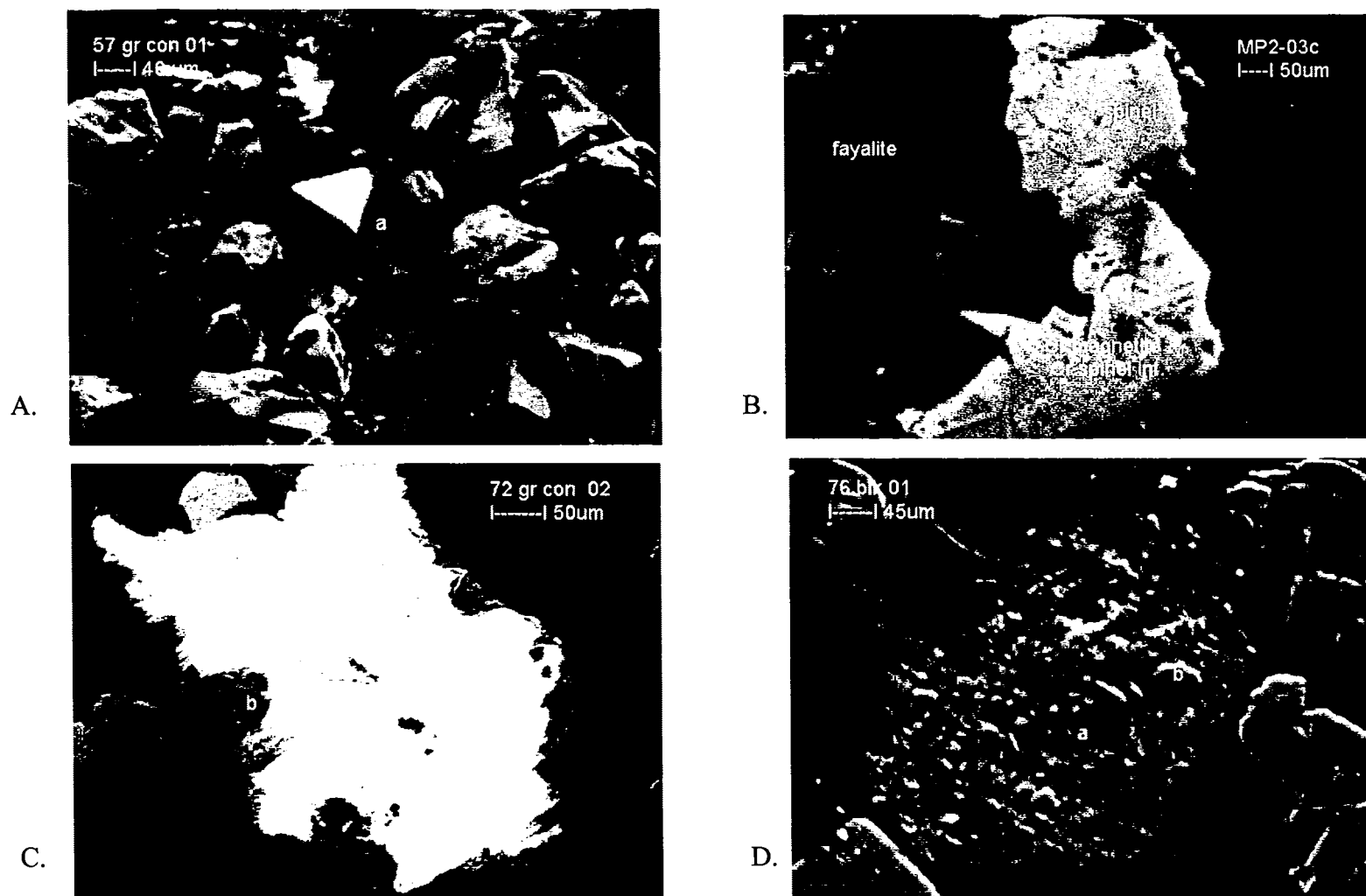


Figure 2. Selection of BSE images that show representative textures of chrome-bearing phases.

		%Cr
A.	98182357, B98-13, Silt Unit	57
B.	98182356, B98-13, Silt Unit	15
C.	98182372, B98-12, Silt Unit	4.6
D.	98182376, B98-12, Aquifer Unit	0.5

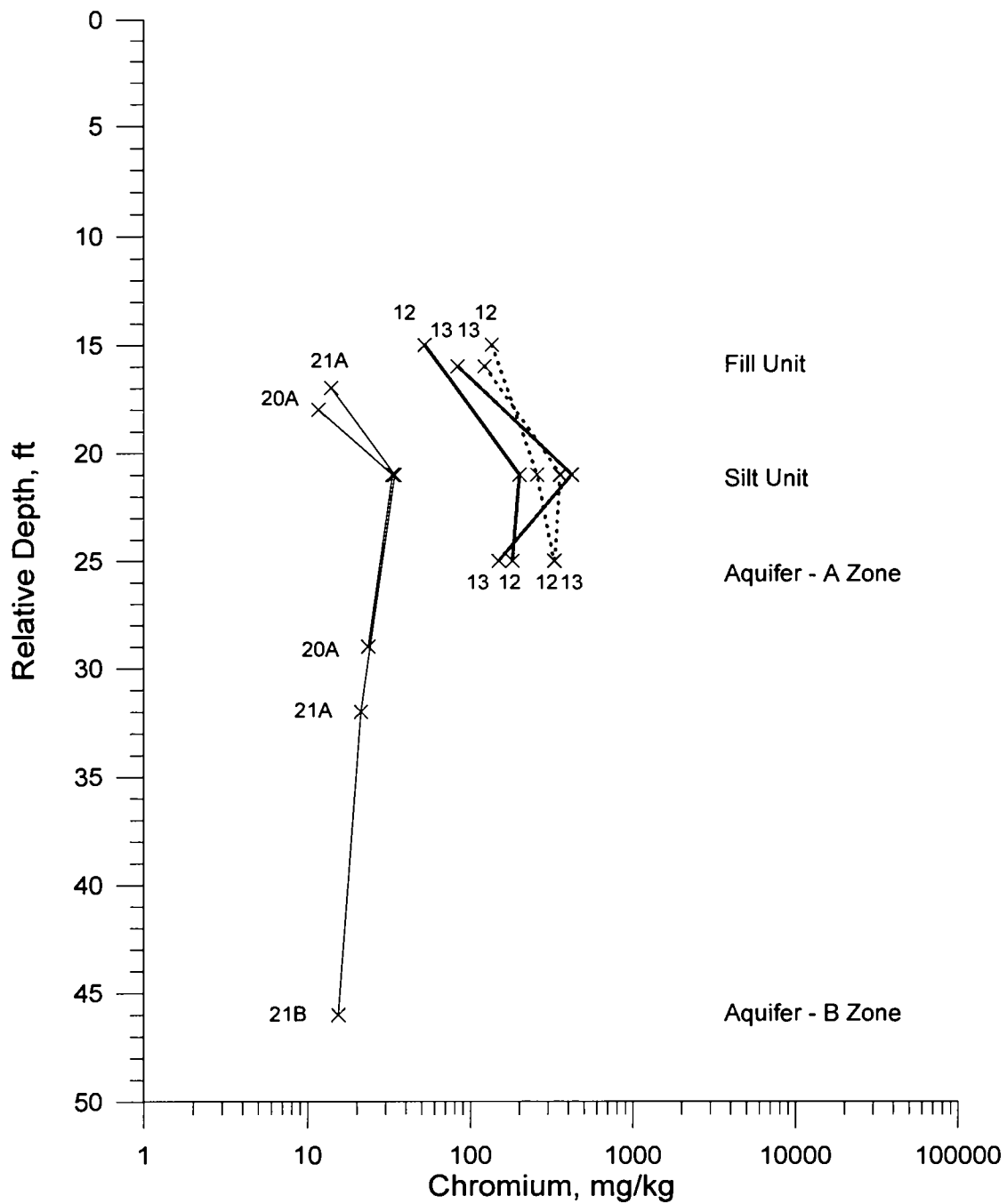


Figure 3. Distribution of chromium concentration with relative depth. Concentration profiles are labeled for boreholes B98-13, B98-12, B98-20A, B98-21A, and B98-21B (deep). Solid lines are for bulk samples from all wells; dotted lines are for the combined silt and clay size fractions from B98-13 and B98-12. Depths are normalized relative to the Silt Unit in B98-13 at 21 ft.

Tables

1. Field sample and corresponding laboratory sample numbers
2. Inorganic analyses of soil samples
3. Phases discussed in report and appendices
4. Summary list of minerals identified by XRD
5. Summary list of minerals identified by SEM/EPMA

Table 1. Field samples and corresponding laboratory size-separates selected for mineralogical analysis by x-ray diffraction (XRD) and scanning electron microscopy/electron microprobe (EM). Field lithologic descriptions by Roy F. Weston (1999) are in bold.

Lab Number EPA	Field Number Weston	Size Fraction mm	Cum Size cum%	XRD analysis	EM analysis
Borehole B98-13					
Fill Unit at 16 ft		silty sand with gravel			
98184301	SBR1-9813-0160	field sample			
98182379	SBR1-9813-0160	4 cut pebbles		x	
98182350	SBR1-9813-0160	>2	47.3	x	x
98182351	SBR1-9813-0160	0.5-2	20.6		x
98182352	SBR1-9813-0160	0.07-0.5	18.2	x	x
98182353	SBR1-9813-0160	<0.07	13.9	x	
Silt Unit at 21 ft		silt			
98184302	SBR1-9813-0210	field sample			
98182380	SBR1-9813-0210	1 cut pebble			
98182354	SBR1-9813-0210	>2	16.6	x	
98182355	SBR1-9813-0210	0.5-2	5.1	x	
98182356	SBR1-9813-0210	0.07-0.5	14.7	x	x
98182357	SBR1-9813-0210	<0.07	63.5	x	x
Silt Unit at 21 ft		silt			
98184302DU	SBR1-9813-0210	field sample			
98182381	SBR1-9813-0210	1 cut pebble			
98182358	SBR1-9813-0210	>2	15.8		
98182359	SBR1-9813-0210	0.5-2	7.6		
98182360	SBR1-9813-0210	0.07-0.5	9.7	x	
98182361	SBR1-9813-0210	<0.07	66.9	x	
Aquifer A-zone at 25 ft		silty gravel			
98184303	SBR1-9813-0250	field sample			
98182382	SBR1-9813-0250	6 cut pebbles			
98182362	SBR1-9813-0250	>2	55.3		
98182363	SBR1-9813-0250	0.5-2	9.1		
98182364	SBR1-9813-0250	0.07-0.5	12.7	x	x
98182365	SBR1-9813-0250	<0.07	23.0	x	x
Borehole B98-12					
Fill Unit at 16 ft		silt with gravel			
98184304	SBR1-9812-0160	field sample			
98182383	SBR1-9812-0160	7 cut pebbles		x	
98182366	SBR1-9812-0160	>2	32.6		
98182367	SBR1-9812-0160	0.5-2	24.5		
98182368	SBR1-9812-0160	0.07-0.5	24.4	x	
98182369	SBR1-9812-0160	<0.07	18.5	x	
Silt Unit at 22 ft		silt			
98184305	SBR1-9812-0220	field sample			
98182384	SBR1-9812-0220	2 cut pebbles			
98182370	SBR1-9812-0220	>2	20.1		
98182371	SBR1-9812-0220	0.5-2	6.0		
98182372	SBR1-9812-0220	0.07-0.5	12.7	x	x
98182373	SBR1-9812-0220	<0.07	61.2	x	
Aquifer A-zone at 26 ft		silty gravel			
98184306	SBR1-9812-0260	field sample			
98182385	SBR1-9812-0260	8 cut pebbles			
98182374	SBR1-9812-0260	>2	49.8		
98182375	SBR1-9812-0260	0.5-2	8.4		
98182376	SBR1-9812-0260	0.07-0.5	15.2	x	x
98182377	SBR1-9812-0260	<0.07	26.6	x	x

Table 2. Inorganic analyses of soil samples collected April-May, 1998, Frontier Hard Chrome site (from Weston, 1999).

lab number	sample	al	sb	as	ba	be	cd	ca	cr	cr6	co	cu	fe	pb	mg	mn	ni	k	se	na	th	va	zn
	borehole-depth	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
Bulk Samples																							
98184301	13-16	18600	4.5	5.3	172	0.918	0.3	8060	83.2	4	13.4	33.1	36400	285	4630	505	23.4	1200	10	468	4	116	162
98184302	13-21	24500	4.5	5.1	209	1.35	0.44	8500	421	26.1	17.6	65.4	40900	26.1	5960	1190	32.5	1560	10	341	4	97.8	112
98184302d	13-21dup	23300	4.5	5.7	204	1.35	0.3	8380	420		17.9	64.8	40000	24.3	5800	1210	32.1	1470	15	321	4	96.1	111
98184303	13-25	21400	4.5	4	234	1.05	0.2	5030	149	17.8	14.8	33.3	37800	9.1	4890	640	21.1	1120	10	475	4	117	75.3
Fine Fraction																							
98182353	13-16	40500	4.5	4.8	388	1.55	1.31	11800	122		15.5	142	45000	257	4770	922	27.4	1840	10	452	4	117	390
98182357	13-21	29300	4.5	8	207	1.4	0.23	7320	360		9.07	55.3	38100	39.4	5770	357	28.7	1460	14	249	4	78.5	116
98182361	13-21dup	25700	4.5	10	210	1.34	0.27	8430	355		11.3	47.4	38900	42.8	5930	503	28	1690	11	284	4	83.8	122
98182365	13-25	39200	4.5	4	427	1.5	0.3	5740	331		16.9	56.5	43500	33.8	5770	897	28	1590	10	330	4	103	105
Bulk Samples																							
98184304	12-16	12200	4.5	4	130	0.691	0.75	27700	52	4	11.3	34.3	30600	254	4290	395	21.7	869	10	635	4	85.9	161
98184305	12-22	19400	4.5	4	192	1.21	0.52	7290	200	4	13.8	73.1	43000	46.6	5390	457	26.1	1570	10	388	4	89.1	120
98184306	12-26	20000	4.5	6.4	188	1.18	0.2	5370	181	11.6	14.1	28.9	38100	8.7	5060	474	25.2	1090	10	471	4	125	74.6
Fine Fraction																							
98182369	12-16	25400	4.5	7.2	325	1.06	1.6	45200	135		15.7	74.3	38400	729	5510	740	31.6	1540	10	746	4	101	336
98182373	12-22	25000	4.5	4.6	230	1.43	0.56	7380	257		14	47.6	37400	58.2	5980	459	25	1700	10	343	4	95.8	134
98182377	12-26	31100	4.5	4	275	1.46	0.23	5900	327		16.5	42.3	40100	15.4	5550	635	26.9	1380	11	385	4	108	88.7
Bulk Samples																							
98184307	21A-7.5	11800	4.5	4	104	0.62	0.2	3630	13.9		8.83	14.1	22200	21.6	2830	323	12.7	593	10	384	4	66.4	61.4
98184308	21A-12	28500	4.5	11	229	1.63	0.2	5550	34.1		16.3	30.7	39500	13	6750	778	24.6	1270	10	255	4	102	84.4
98184309	21A-22.5	15300	4.5	5.6	150	1.16	0.2	6250	21.2		14.3	27.2	39900	7.5	5120	520	19.1	1150	10	730	4	131	68.9
Fine Fraction																							
98184310	20A-6.5	5650	4.5	4	71	0.36	0.2	2710	11.6		5.58	8.26	13400	4.8	2430	182	10.4	579	10	312	4	36.9	42.6
98184311	20A-10	26600	4.5	5.5	239	1.58	0.28	5830	33		15.3	32.3	35400	14	6620	820	26.9	1420	10	281	4	87.5	81.8
98184312	20A-17.5	19100	4.5	5.4	170	1.15	0.2	5180	23.5		13.3	23.2	35600	5.7	4620	474	18.4	815	10	658	4	111	63.8
98224550	21B-38	7370	4.5	4.8	83.8	0.526	0.2	3620	15.4		8.64	15.5	18900	4.5	5460	277	20.6	1040	10	331	4	46.2	35.8
mg/L																							
98182378	sieve blank	20	45	40	1	1	2	70.6	5		5	9	10	25	25	1.1	10	700	100	87.7	40	3	9.5
98182378d	sieve blank dup	20	45	40	1	1	2	70.7	5		5	8.2	10	25	20	1.3	10	700	100	87.3	40	3	11
detection limit																							

Table 3. Phases discussed in this report. The abbreviations and analytical procedures (XRD or EM) are noted. Phases described by EM that are not discrete identifiable minerals are noted by --. The phase, FeAlSi, is placed under clay minerals because of the fine-grained texture apparent in SEM images.

XRD	EM	SILICATES		IDEAL FORMULA
		Silica		
x		QZ	quartz	SiO ₂
x		CR	cristobalite	SiO ₂
		Other Silicates		
x		FS	feldspar	(K,Na,Ca)Al(Al,Si) ₃ O ₈
x	x	PX	pyroxene	(Ca,Mg,Fe) ₂ (Si,Al) ₂ O ₆
x	x	AM	amphibole	(Na,Ca) ₂ (Mg,Fe) ₅ Si ₈ O ₂₂ (OH) ₂
x		MI	mica	K(Al,Mg,Fe) ₂₋₃ (Al,Si) ₄ O ₁₀ (OH,F) ₂
	x	FA	fayalite	Fe ₂ SiO ₄
		Clay Minerals		
x		IL	illite	(K,Na,Ca)(Mg,Fe,Al) ₂₋₃ (Al,Si) ₄ O ₁₀ (OH) ₂
x		SM	smectite	Ca _{0.5} (Mg,Fe) ₃ (Si,Al) ₄ O ₁₀ O(OH) ₂ ·4H ₂ O
x		CH	chlorite	(Mg,Fe) ₆ AlSi ₃ O ₁₀ (OH) ₈
x		KA	kaolinite	Al ₂ Si ₂ O ₅ (OH) ₄
	x	FeAlSi	iron-bearing aluminum silicate --	
		OXIDES		
x	x	MT	magnetite	Fe ₃ O ₄
x		MH	maghemite	Fe ₂ O ₃
x	x	CT	chromite	FeCr ₂ O ₄
	x	ILM	ilmenite	FeTiO ₃
	x	TMT	titanomagnetite	Fe(Fe,Ti) ₂ O ₄
	x	SP	spinel	MgAl ₂ O ₄
	x	FeHox	iron hydroxide	--
		CARBONATES		
x		CA	calcite	CaCO ₃
x		AR	aragonite	CaCO ₃
x		VT	vaterite	CaCO ₃
	x	SI	siderite	FeCO ₃
		METALS		
	x	FE	iron or steel	--
	x	Cr/Ti	chromium/titanium phase --	

Table 4. Summary list of minerals as identified by x-ray diffraction (Appendix A).

Explanation:					
Phases	am-amphibole ar-aragonite ct-cristabolite	ca-calcite ch-chlorite fs-feldspar	il-illite ka-kaolinite mi-mica	mt-magnetite px-pyroxene qz-quartz	sm-smectite vt-vaterite
Amount of phases	major mineral +++	minor mineral ++	trace mineral +		
Not Analyzed	--				

Borehole Depth	silica qz ct		silicate fs px/am mi			clay mineral il sm ch ka				oxide mt	carbonate ca ar vt			
B98-13 16 ft 21 ft 21 ft dup 25 ft B98-12 16 ft 22 ft 26 ft	Silt and Clay Size Fraction (<0.07 mm)													
	+++	+	+++	+	+	+	+	+		+	+			
	+++	+	+++	+	++	++	++	++	+	+				
	+++	+	+++	+	++	++	+	++	+	+				
	+++	+	+++	+	++	++	++	++						
	+++	+	+++	+	+	+	+	+		+	++			
	+++	+	+++	+	+	+	++	++		+	++			
	+++	+	+++	+	++	++	++	++	+	+	+			
	B98-13 16 ft 21 ft 21 ft dup 25 ft B98-12 16 ft 22 ft 26 ft	Fine Sand Size Fraction (0.07-0.5 mm)												
		+++		+++	+	+			+		+	+		
+++		+	+++	++	++		++	++		+				
+++		+	+++	+	++		++	++		+	+			
+++			+++	+	++		++	++		+	++			
+++		+	+++	+	+			+		+	+			
+++		+	+++	++	++		++	++		+	+			
+++		+	+++	+	++		++	++		+	+			
B98-13 21 ft B-98-13 16 ft 21 ft B98-12 16 ft B-98-13 21 ft		Sand and Gravel Size Fraction (>0.5 mm)												
		orange oxide-coated grains												
	+++		++	+	+		+	+						
	white carbonate-coated grains													
	++	++	+++				+				+++		+	
	++	+	+++	+			+				+++		+	
	+++	++	+++				+				+++	++	+	
	black uncoated basalt grains													
	+	+	+++	++			+			+				

Table 5. Summary list of minerals containing chromium and manganese in samples from Frontier Hard Chrome, as identified by scanning electron microscopy/electron microprobe analysis (see Appendix B).

Explanation:		
Phases	am-amphibole cr/ti-chromium/titanium phase ct-chromite fa-fayalite fe-iron or steel fealsi-iron-bearing aluminum silicate fehox-iron hydroxide.	px-pyroxene il-ilmenite mt-magnetite tmt-titanomagnetite or titanian magnetite si-siderite sp-spinel
Amount of phases	common phase ++ rare phase +	
Amount of element in phases	Cr and Mn occur in major to minor amounts where shaded, and trace amounts where not shaded.	
Not Analyzed	--	

Borehole Depth	Chromium-bearing Phases									Manganese-bearing Phases								
	px/am	fealsi	fehox	mt	ilm	tmt	ct	fe	other	px/am	fealsi	fehox	mt	ilm	tmt	ct	fe	other
Silt and Clay (<0.07 mm)										Silt and Clay (<0.07 mm)								
B98-13																		
16 ft	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
21 ft		++				+	+				++				+	+		
25 ft						+	+	+							+	+	+	
B98-12																		
16 ft	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
21 ft	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
25 ft		+				+					+				+			
Fine Sand (0.07-0.5 mm)										Fine Sand (0.07-0.5 mm)								
B98-13																		
16 ft			+			+	+					+	+	+	+			
21 ft	+	++		+	+	+	+	+	sp	+	++		+	+	+	+	+	
25 ft	+	+			+	+		+	cr/ti	+			+	+	+		+	
B98-12																		
16 ft	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
21 ft	+	++	+			+		+	si	+	++			+	+		+	si
25 ft		+									+							
Sand and Gravel (>0.5 mm)										Sand and Gravel (>0.5 mm)								
B98-13																		
16 ft	+			+		+			fa?				+	+	+			

Appendices

- A. Laboratory Report for X-ray Diffraction Analysis
- B. Laboratory Report for Scanning Electron Microscope/Probe Microanalysis

APPENDIX A

Laboratory Report for X-ray Diffraction Analysis.




UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION 10
1200 Sixth Avenue
Seattle, Washington 98101

Reply To
Attn of OEA-095

MEMORANDUM

May 17, 1999

SUBJECT: Frontier Hard Chrome site, Vancouver, Washington - X-ray diffraction analysis of laboratory-prepared separates 98182379-85 from borehole samples 98184301-06

FROM: David Frank 
Office of Environmental Assessment

To: Bernie Zavala
Office of Environmental Assessment

Ken Marcy
Office of Environmental Cleanup

This memorandum provides documentation of x-ray diffraction (XRD) analysis of laboratory-prepared separates from six borehole samples from B98-12 and B98-13. Analysis was by Method XRD-QL (USEPA Manchester Laboratory, version October 1, 1997) which consists of qualitative identification of minerals and other compounds.

SAMPLES

Six samples for chemical and mineralogical analysis were collected from boreholes B98-12 and B98-13 by Mark Pugh and Sonia Fernandez, Roy F. Weston, Inc., April 27, 1998 (Roy F. Weston, 1999). The boreholes were located 100-200 feet southeast of the Frontier Hard Chrome building, and approximately 3000 ft north of the Columbia River. The boreholes were drilled with an 8-inch hollow-stem auger. Samples were collected with 2.5-inch inside-diameter split-spoon sampler. Soil boring logs and sampling procedures are described by a Roy F. Weston (1999) Technical Memorandum. Two 32-oz jars for mineralogical analysis, accompanied by 4-oz jars for chemical analysis, were received for each sample by the Manchester Laboratory under chain-of-custody on April 29, 1998.

Seven additional samples were collected by Roy F. Weston, Inc. from boreholes B98-20A and B98-21A on April 30, and borehole B98-21B on May 28, approximately 900 feet south and downgradient of B98-12 and B98-13. These samples were submitted for chemical analysis and archived for possible mineralogical analysis pending review of the chemical data. Mineralogical analysis of the latter samples was not conducted because of their low chromium content.

For the samples that underwent mineralogical analysis, Table 1 lists the sample numbers, depths, and unit descriptions as used by Roy F. Weston (1999). Three units were sampled in each of two boreholes, B98-13 and B98-12. The units include fill at a depth of 16 feet, silt at 21-

22 feet, and the Aquifer A-zone at 25-26 feet. In order to provide information on variability within a sampled unit, two portions of the sample from the Silt Unit (SBR1-9813-0210) from borehole B98-13 were prepared for analysis. Therefore a total of six field samples and one duplicate were carried through the mineralogical procedures.

SAMPLE PREPARATION

The borehole samples were separated into five size fractions at the Manchester Laboratory according to the flow sheet in Figure 1. The purpose of the size fractionation was to concentrate secondary minerals. Prior to size separation, the samples were mixed and 100 g withdrawn for examination of water-soluble phases and for archiving. Then 500 g were withdrawn for size separation by wet sieving. Size fractions include gravel (>2 mm), coarse sand (0.5-2 mm), fine sand (0.07-0.5 mm), and silt and clay (<0.07 mm). The gravel fraction was further divided at about 10 mm into larger gravel and smaller gravel. No gravel fragments were larger than about 20 mm.

Each size fraction was assigned a new lab number for a total of 35 laboratory samples generated from the original six field samples and one duplicate sample. In addition a sieve blank of deionized water was collected to determine the potential contribution of metals from the sieve materials. The size separates were well mixed and split for optical microscopy and x-ray diffraction analysis at the Manchester Laboratory, and for scanning electron microscopy/electron probe microanalysis at Cannon Microprobe, Seattle. The larger gravel clasts (>10 mm) were split with a diamond saw. The remaining sand and gravel fractions were split with a riffle splitter, and the silt and clay fractions were split by quartering. Table 2 lists the sample numbers and the weight and percentage results from size separation. Figure 2 shows the cumulative size distribution.

METHODS

XRD analysis was done on bulk material from the fine sand and silt-and-clay fractions, and on hand-picked clasts, rims, and coatings from the coarse sand and gravel fractions. A Scintag X1 powder diffractometer was used for XRD analysis. Mineral concentrates based on magnetic response were made to aid in mineral identification. Magnetic separations were made with a Frantz LB-1 magnetic barrier separator. Separation of the finest fractions was accomplished by vacuum filtration of re-suspended particulates in deionized water onto 0.45 μ m cellulose filters. A Wild M5-A stereomicroscope was used for optical microscopy with incident light in order to describe and document samples.

Most of the x-ray diffraction mounts were prepared by crushing a few hundred milligrams of material to a fine powder and side-packing into sample holders. Mounts were also prepared by dusting smaller amounts of material onto glass slides or onto low-background plates of single-crystal quartz or silicon. Some mounts were prepared from fine sediment deposition onto 0.45 μ m cellulose filters.

Diffraction patterns were acquired using $\text{CoK}\alpha$ radiation at a wavelength of 1.78897 angstroms (\AA), generated at 36 ma and 45.kv. Screening diffractograms were recorded at a low resolution scan speed of 15 degrees of two-theta ($^{\circ}2\theta$) units per minute over a 2-76 degree range. High-resolution diffractograms were recorded at a scan speed of 0.5-1.0 $^{\circ}(2\theta)$ per minute over the same range. In addition, several diffractograms were acquired early in the project with $\text{CuK}\alpha$ radiation at 1.54056 \AA . A change to cobalt radiation was made to provide greater resolution for clay minerals. Table 2 notes those samples for which diffraction data were collected. Sixty diffraction patterns were recorded for the analysis. Twelve annotated XRD patterns-of-record are included in this documentation. Phase identifications were based on comparing these diffraction data with the database of diffraction peaks maintained by the International Centre for Diffraction Data (1996), and with other x-ray diffraction or mineralogical references from the literature as noted. Clay mineral identifications were based on Brindley and Brown (1980) and Moore and Reynolds (1986).

Quality control checks for this project include the following:

1. The alignment of the goniometer was performed at the beginning of the project with NIST Standard Reference Material 1976, a flat plate of sintered alumina provided by the National Institute of Standards and Technology.
2. The alignment of the goniometer was checked at the beginning of each day of data collection with the measurement of the 3.34 \AA (101) peak of a cryptocrystalline quartz reference plate (novaculite).
3. The alignment of the goniometer for each specimen was checked with the peaks for diagnostic minerals which provided an internal reference. Quartz was abundant in all of these samples and therefore provided the most useful internal reference for alignment.
4. The stability of the x-ray intensity was checked at the beginning of each day of data collection by monitoring the peak height of the 3.34 \AA (101) peak of the quartz reference plate.

RESULTS

The XRD results are listed in Table 3. Fourteen minerals were identified. Attachment 1 contains Table A1 from which Table 3 was condensed. Table A1 lists identified phases and corresponding Powder Diffraction File card numbers of matching phases in the ICDD PDF-2 database. Attachment 2 contains annotated XRD diffraction patterns that provide examples of the identifications for each phase listed in Table 3. Attachment 3 contains notes on microscopic observations under incident light at low power.

The phases in Table 3 are listed by mineral name and ideal chemical formula. Although some compounds found in these samples, such as fragments of concrete, are usually not

considered natural minerals by definition, they are listed in Table 3 by their mineral analog for convenience of discussion. The associated chemical formulae noted for each compound is ideal. As is common for natural minerals, the actual chemical formula may deviate from the ideal because of elemental substitution.

The list is grouped by six general types of phases including three forms of silicate minerals (silica, other silicates, and clay minerals), oxides, carbonates, and amorphous material. The abundance of each phase is denoted in a qualitative manner as a major (M), minor (X), or trace (T) amount based on the intensity of diagnostic diffraction peaks. Corresponding numerical values are approximately greater than 20% by weight for major, 5-20% for minor, and less than 5% for trace. Most phases less than 1-5% in these samples may not be identifiable by the technique used. Diagnostic peaks used for estimating abundance values are circled in the annotated diffractograms in Attachment 2. The diffractograms are annotated for mineral designation and d-spacing for key peaks.

Results are provided in Table 3 for the silt and clay fractions (<0.07 mm) and fine sand fractions (0.07-0.5 mm) for all of the borehole samples. Results are also listed for separations of selected larger grains which had coatings or alteration rims. Coatings are material whose texture indicate secondary deposition onto the outside of a grain by mineral precipitation. Alteration rims have a texture indicating secondary mineral reaction within the margin of a grain such as by weathering. Where noted, the distinction was made by microscopic observation. For the largest gravel fragments, the coatings were scraped off and analyzed separately. None of the coatings were thick enough to be able to analyzed in a pure form, but rather were concentrated along with a variable amounts of the underlying rock matrix.

The borehole samples consist of granular material that spans a size range from clay to pebbles. The Fill Unit has the coarsest material, and the Silt Unit has the finest. Samples from the Fill Unit have primarily dark gray to black sand and gravel with about 14-19% fines of silt and clay (Figure 2). Samples from the Silt Unit have dark gray to dark grayish brown silt and clay with 61-67% fines. Samples from the Aquifer Unit have dark brown to dark grayish brown sand and gravel with 23-27% fines.

Visual examination of the gravel fractions indicate the most common rock types in these samples are black basalt, gray andesite, and white to beige granitic material, perhaps granodiorite, or quartzite. The Fill Units from both boreholes contained calcite-coated pebbles from chunks of concrete. The Fill also has a large proportion of angular basalt. Many of the basalt pebbles in the Fill Unit are coated with a sticky tar-like material that resembles asphalt. The Silt and Aquifer Units have a much smaller proportion of angular pebbles than the Fill Unit, though angular basalt fragments are still common in the Silt Unit.

Silicate Phases

Two silica minerals were identified, quartz and cristobalite. Quartz occurs as a major

mineral in all of the bulk samples (Attachment 2, diffractogram D-1), though it is sparse in separations of the basalt fragments. Cristobalite also occurs in the bulk samples in trace amounts (D-2), and is more abundant in the white coatings of concrete. Other silicates identified in all the bulk samples are major feldspar (D-3), and minor to trace pyroxene (D-4), amphibole (D-5), and mica (D-6). No attempt was made to further distinguish specific members of these mineral groups, although microscopic observation indicated the presence of hornblende in the amphibole group, and both muscovite and biotite in the mica group. A variety of silicate clay minerals were identified and are discussed separately below.

Carbonate Phases

Calcite was found primarily as a component of white coatings on pebbles (D-7). In the Fill Unit, some of the coatings were relatively thick 1-3 mm and commonly entrained other rocks indicating that the coatings were remnants of concrete. Calcite would not be expected to be a primary phase in concrete, but could form as a weathering product. Two other carbonates, aragonite (D-8) and vaterite (D-9), were found with calcite in coatings in the Fill Unit and less commonly in the Silt Unit. Vaterite has been reported elsewhere to be an alteration product of concrete. Minor to trace calcite was also identified in the bulk samples of the deeper units.

Oxide Phases

The only oxide that was identified was magnetite (Fe_3O_4) in trace amounts. Magnetite may mask other spinel-type phases, one of which is chromite. Magnetic separation was used to remove the magnetite component in an attempt to determine if chromite could be detected. Chromite was not abundant enough to be detected in the magnetic separates.

Clay Minerals

A variety of clay minerals, illite, chlorite (D-10), smectite, and kaolinite, were identified in all of the samples. The most abundant clay minerals were in the Silt Unit, less in the Aquifer Unit, and trace amounts in the Fill Unit. Diagnostic treatments were conducted on samples from the Fill and Aquifer Units to expand the clays with ethylene glycol, and contract them with heat in order to verify the presence of the different clay groups (Figure 3). Illite was identified by a 10 Å peak that persisted after heating to 550°C. Likewise chlorite was identified by persistent 7 Å and 14 Å peaks with the same heating. Kaolinite lost its structure with heating, and smectite had diagnostic expansion with glycol.

The relative abundance of the different clays was determined by comparison of the peak heights in oriented specimens with the modeled peak heights in clay mixtures using the method of Reynolds and Reynolds (1996). The model that best fit the measured diffraction peaks consisted of a mixture of the four clays, rather than an interstratification. Among the clay minerals in the Fill Unit, the approximate order of abundance is illite, chlorite, smectite, and kaolinite. In the Aquifer Unit, smectite appears to be more abundant than chlorite, though illite

remains dominant. Illite comprises about half of the clay mineral content.

Illite is a potassium-rich aluminum silicate that can be considered a clay-size mica phase. In contrast with ideal muscovite, illite is deficient in potassium and consequently allows substitution of other metals including iron. Chlorite and smectite are magnesium- and/or iron-rich aluminum silicates. Smectite is an expanding clay and generally the finest grained variety of this group. Kaolinite is an aluminum silicate. Of these clay minerals, the types that are likely to be most abundant in iron are chlorite and smectite, and to a lesser extent illite. Together, the chlorite and smectite make up about 30-40% of the clay mineral content in the silt and clay fraction. In the coarser size fractions, coatings were examined for clay minerals. One concentrate of orange-oxide coated grains contained trace, but elevated amounts of both smectite and chlorite.

Chromium- and Manganese-bearing Phases

A particular search was made for secondary chromium-bearing phases. Focused methods included size separation to concentrate the fines, which would be expected to also concentrate secondary minerals. The size separation was very helpful in identification of the clay minerals, but no discrete chromium phases were abundant enough to be identified in the silt and clay fraction. Coatings, which would also be expected to have secondary minerals, were examined and concentrated. Calcite coatings were the most abundant, but they also did not yield identifiable chromium-bearing phases. Magnetic separations of the sample from the Silt Unit at B98-13 were made, as well, in an unsuccessful attempt to produce a chromium concentrate. Since no discrete chromium mineral was identified by x-ray diffraction, any such minerals if present would likely occur at a concentration of less than 5%.

In addition, manganese-bearing phases were particularly sought. As with chromium, any manganese minerals present were not concentrated enough to be identifiable by XRD.

Summary of the Distribution of Phases

Common rock-forming minerals, quartz, feldspar, pyroxene, amphibole, and mica are distributed as major and minor minerals in all three units of each borehole. The Fill Unit contains major calcite and trace aragonite and vaterite in coatings associated with remnants of concrete. Vaterite was also detected in coatings in the Silt Unit suggesting that it has entrained concrete fragments in the area of Borehole B98-13. The Fill Unit at both boreholes also contains abundant asphalt covered pebbles of angular basalt.

With reference to the size distribution (Figure 2), the Silt Unit contains over 60% silt- and clay-size grains for which XRD indicates the presence of abundant clay minerals. Prominent among the clay minerals are those that are potentially iron-bearing, chlorite, smectite, and illite. Lesser kaolinite also occurs in the Silt Unit. The type of modeled clay mixture that best fits the measured data is one which lacks interstratification. Lack of interstratification indicates that the

clay minerals are detrital rather than authigenic. In other words, they do not represent secondary mineralization at the site, but rather were transported into the area by fluvial processes. The Aquifer Unit contains a similar group of clay minerals, but in somewhat less amount.

No discrete chromium- or manganese-bearing phases were found, indicating that any such minerals are less than 5% in concentration. Of the minerals identified, those most likely to provide reactive sites for chromium are the clay minerals which tend to incorporate iron, particularly chlorite and smectite.

REFERENCES

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FIGURES

Figure 1. Flow sheet of sample preparation procedure.

Figure 2. Size distribution of borehole samples.

Figure 3. X-ray diffractograms of clay minerals in the Silt and Aquifer Units.

Sample Preparation - Frontier Hard Chrome Mineralogy

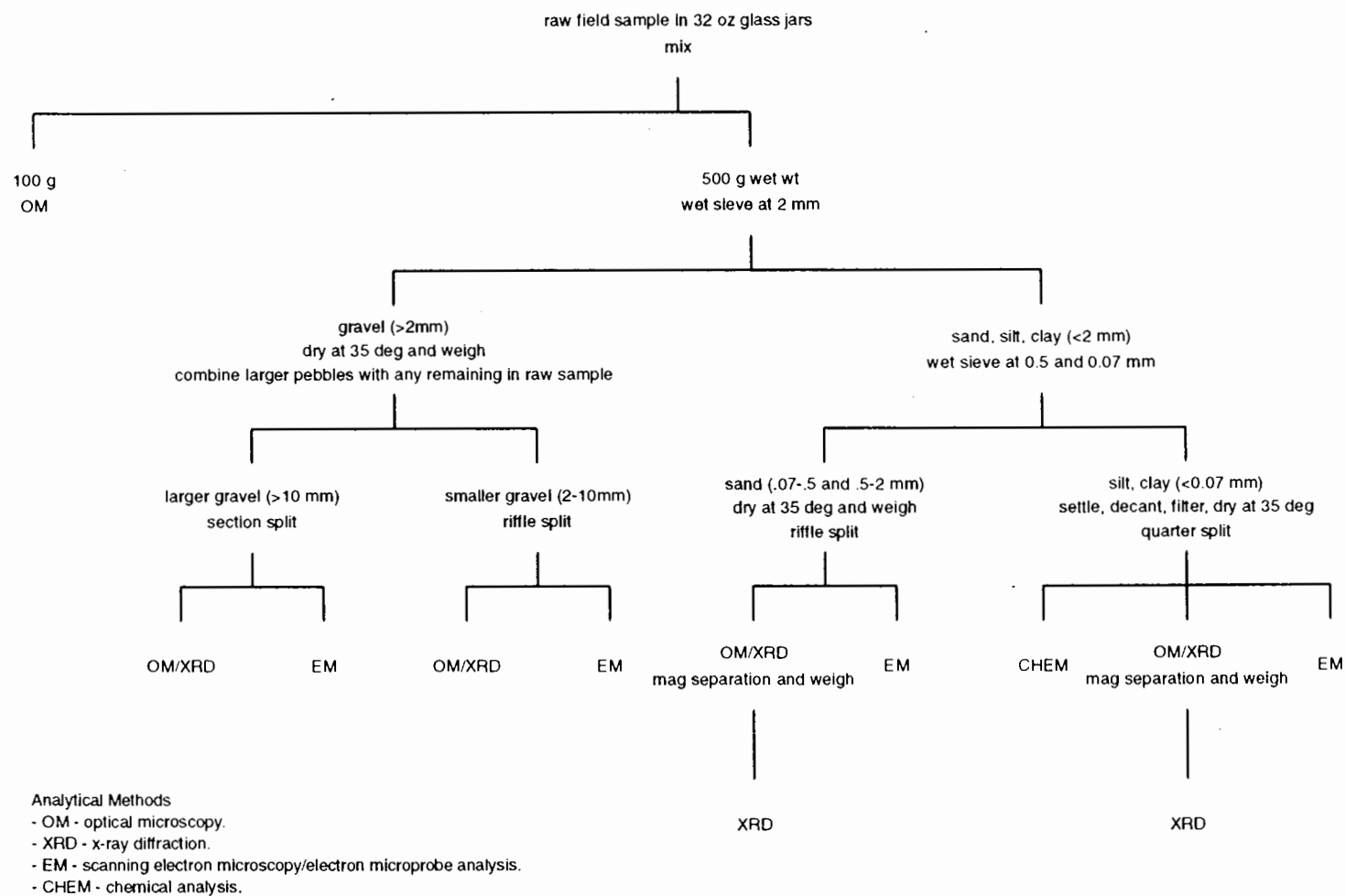


Figure 1. Flow sheet for the sample preparation procedure for mineralogical analysis. Separate jars of the same field sample were also submitted for chemical analysis.

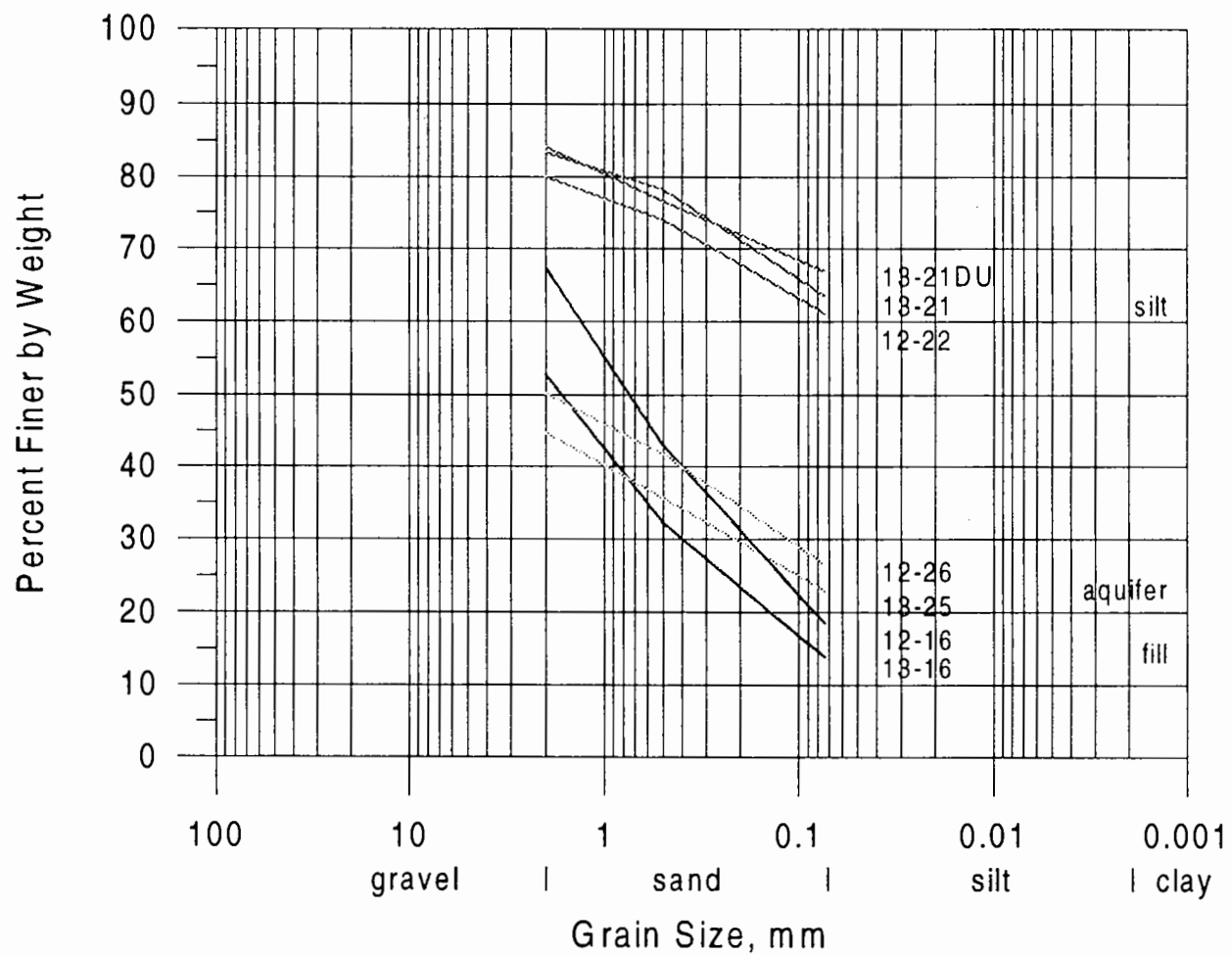


Figure 2. Size distribution of <20 mm fraction of borehole samples for the Frontier Hard Chrome site. Samples are labeled by borehole and depth; 12-26 designates borehole B98-12 at a depth of 26 ft.

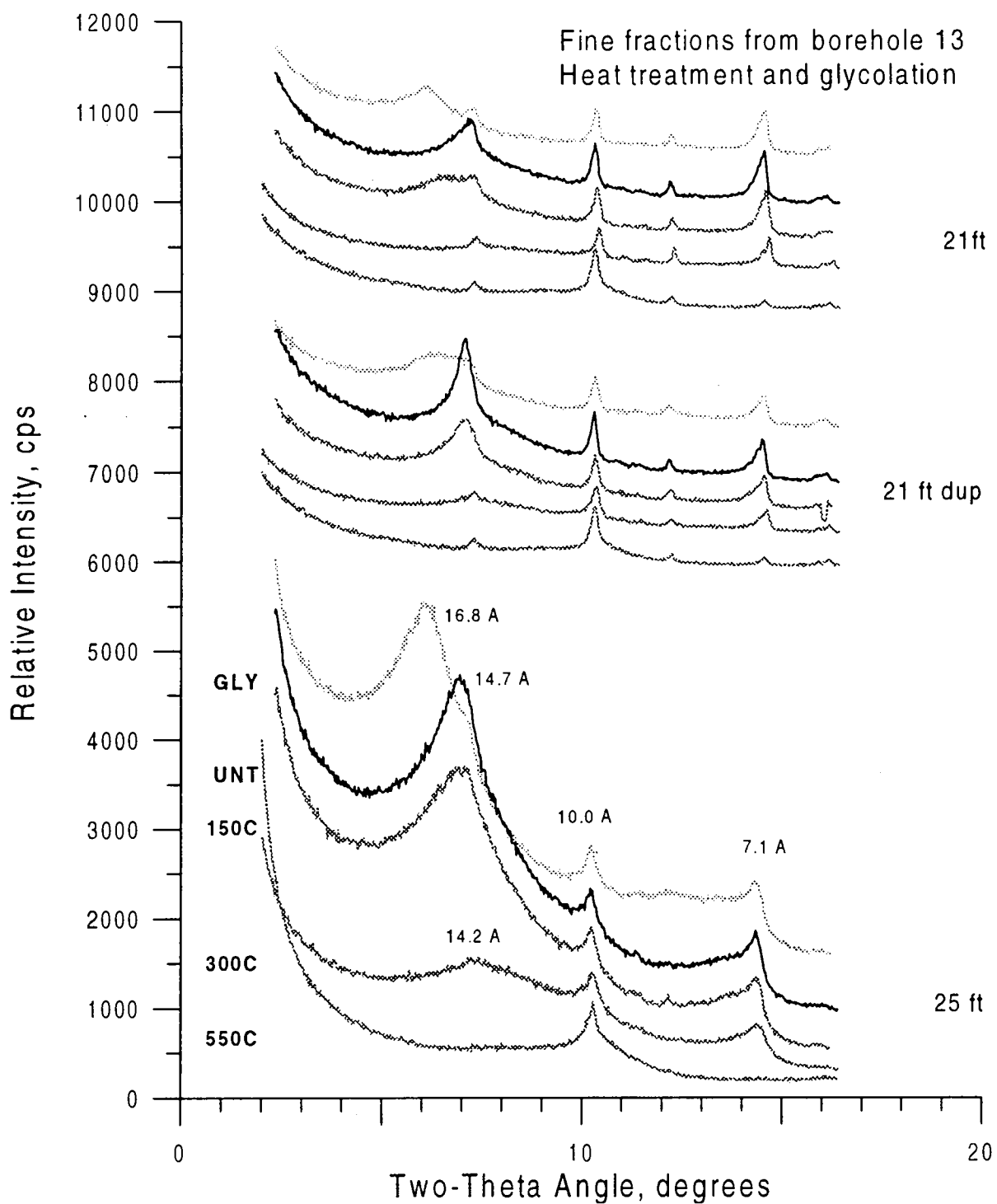


Figure 3. X-ray diffractograms of clay minerals in the Fill and Aquifer Units.

TABLES

Table 1. Field samples and lithologic units.

Table 2. Field samples and corresponding laboratory size-separates.

Table 3. List of phases identified by x-ray diffraction.

Table 1. Field samples and lithologic units, from Roy F. Weston (1999).

Borehole	Roy F. Weston field Sample Number	EPA lab Sample Number	Depth	Unit	Lithologic Description
B98-13	SBR1-9813-0160	98184301	16	Fill	silty sand with gravel
B98-13	SBR1-9813-0210	98184302	21	Silt	silt
B98-13	SBR1-9813-0210	98184302 dup	21	Silt	silt
B98-13	SBR1-9813-0250	98184303	25	Aquifer - A-zone	silty gravel
B98-12	SBR1-9813-0160	98184304	16	Fill	silt with gravel
B98-12	SBR1-9813-0220	98184305	22	Silt	silt
B98-12	SBR1-9813-0260	98184306	26	Aquifer - A-zone	silty gravel

Table 2. Field samples and corresponding laboratory size-separates.

Lab Number EPA	Field Number Weston	Depth ft	Grain Size	Wet Weight g wet wt	Dry Weight g @ 35C	Cum Size cum%	Cum Size tot cum%	XRD data
Field Samples								
98184301	SBR1-9813-0160	16	bulk	501	410.			
98184302	SBR1-9813-0210	21	bulk	501	375.			
98184302DU	SBR1-9813-0210	21	bulk	499	372.			
98184303	SBR1-9813-0250	25	bulk	499	405.			
98184304	SBR1-9812-0160	16	bulk	503	359.			
98184305	SBR1-9812-0220	22	bulk	503	396.			
98184306	SBR1-9812-0260	26	bulk	501	418.			
Laboratory Separates								
98182379	SBR1-9813-0160	16	4 cut pebbles					x
98182350	SBR1-9813-0160	16	>2		194	47.3		x
98182351	SBR1-9813-0160	16	0.5-2		85	20.6		
98182352	SBR1-9813-0160	16	0.07-0.5		75	18.2		x
98182353	SBR1-9813-0160	16	<0.07		57	13.9	100.0	x
98182380	SBR1-9813-0210	21	1 cut pebble					
98182354	SBR1-9813-0210	21	>2		62	16.6		x
98182355	SBR1-9813-0210	21	0.5-2		19	5.1		x
98182356	SBR1-9813-0210	21	0.07-0.5		55	14.7		x
98182357	SBR1-9813-0210	21	<0.07		238	63.5	100.0	x
98182381	SBR1-9813-0210	21	1 cut pebble					
98182358	SBR1-9813-0210	21	>2		59	15.8		
98182359	SBR1-9813-0210	21	0.5-2		28	7.6		
98182360	SBR1-9813-0210	21	0.07-0.5		36	9.7		x
98182361	SBR1-9813-0210	21	<0.07		249	66.9	100.0	x
98182382	SBR1-9813-0250	25	6 cut pebbles					
98182362	SBR1-9813-0250	25	>2		224	55.3		
98182363	SBR1-9813-0250	25	0.5-2		37	9.1		
98182364	SBR1-9813-0250	25	0.07-0.5		51	12.7		x
98182365	SBR1-9813-0250	25	<0.07		93	23.0	100.0	x
98182383	SBR1-9812-0160	16	7 cut pebbles					x
98182366	SBR1-9812-0160	16	>2		117	32.6		
98182367	SBR1-9812-0160	16	0.5-2		88	24.5		x
98182368	SBR1-9812-0160	16	0.07-0.5		88	24.4		
98182369	SBR1-9812-0160	16	<0.07		66	18.5	100.0	x
98182384	SBR1-9812-0220	22	2 cut pebbles					
98182370	SBR1-9812-0220	22	>2		79	20.1		
98182371	SBR1-9812-0220	22	0.5-2		24	6.0		
98182372	SBR1-9812-0220	22	0.07-0.5		50	12.7		x
98182373	SBR1-9812-0220	22	<0.07		242	61.2	100.0	x
98182385	SBR1-9812-0260	26	8 cut pebbles					
98182374	SBR1-9812-0260	26	>2		208	49.8		
98182375	SBR1-9812-0260	26	0.5-2		35	8.4		
98182376	SBR1-9812-0260	26	0.07-0.5		64	15.2		x
98182377	SBR1-9812-0260	26	<0.07		111	26.6	100.0	x
98182378	sieve blank			1000				

Table 3. Minerals identified by x-ray diffraction. Material listed includes the silt- and-clay and fine sand fractions (shaded), and selected grains with coatings or alteration rims as noted.

Borehole samples from B98-13 and B98-12, collected April 27, 1998, for the Frontier Hardchrome site. Qualitative abundance designated by major (M), minor (X), trace (T).															
Borehole		B98-13					B98-13					B98-13		B98-13	
Field Number		98184301					98184302					98184302 dup		98184303	
Unit - Depth		Fill Unit - 16 ft					Silt Unit - 21 ft					Fill Unit - 21 ft		Aquifer Unit - 21 ft	
Laboratory Number (last two digits of series 98182350-98182385)		79	50	52	53		54	55	55	56	57	60	61	64	65
Size Fraction *		gravel	gravel	f sand	silt/clay		gravel	sand	sand	f sand	silt/clay	f sand	silt/clay	f sand	silt/clay
Material **		wh ct	bl ct	bulk	bulk		wh ct	bl rim	or ct	bulk	bulk	bulk	bulk	bulk	bulk
PHASE	GENERIC FORMULA														
SILICA															
Quartz	SiO ₂	X	M	M	M		X	T	M	M	M	M	M	M	M
Cristobalite	SiO ₂	X			T		T	T		T	T	T	T		T
SILICATE															
Feldspar	(K,Na,Ca)Al(Al,Si) ₃ O ₈	M	M	M	M		M	M	X	M	M	M	M	M	M
Pyroxene	(Ca,Mg,Fe) ₂ (Si,Al) ₂ O ₆		T	T	T		T	X	T	T	T	T	T	T	
Amphibole ***	(Ca,Na) ₂ (Mg,Fe,Al) ₅ (Si,Al) ₈ O ₂₂ (OH) ₂			T	T					X	T	T	T	T	T
Mica ***	K(Al,Mg,Fe) ₂₋₃ (Si,Al) ₄ O ₁₀ (OH,F) ₂			T	T				T	X	X	X	X	X	X
CLAY MINERALS															
Illite	(K,Na,Ca)(Mg,Fe,Al) ₂₋₃ (Al,Si) ₄ O ₁₀ (OH) ₂				T						X		X		X
Smectite	Ca _{0.5} (Mg,Fe) ₃ (Si,Al) ₄ O ₁₀ (OH) ₂ ·4H ₂ O	T	T		T		T	T	T	X	X	X	T	X	X
Chlorite ***	(Mg,Fe) ₆ AlSi ₃ O ₁₀ (OH) ₈			T	T				T	X	X	X	X	X	X
Kaolinite ***	Al ₂ Si ₂ O ₅ (OH) ₄										T		T		
OXIDES															
Magnetite ***	Fe ₃ O ₄		T	T	T			T		T	T	T	T	T	
CARBONATES															
Calcite	CaCO ₃	M		T	T		M					T		X	
Aragonite	CaCO ₃														
Vaterite	CaCO ₃	T					T								
OTHER															
Amorphous					T						T		T		T
EXPLANATION AND PHASE NOTES															
* Size Fractions: silt/clay (<0.07 mm), f sand (0.07-0.5 mm), c sand (0.5-2 mm), gravel (>2 mm), gravel*-cut pebbles (>10 mm).															
** Material: wh-white, bl-black, or-orange coatings or alteration rims.															
*** Amphibole primarily hornblende.															
*** Mica primarily muscovite; may include some biotite.															
*** Chlorite may include some kaolinite															
*** Magnetite may include maghemite and chromite.															

Table 3. Minerals identified by x-ray diffraction. Material listed includes the silt- and-clay and fine sand fractions (shaded), and selected grains with coatings or alteration rims as noted.

Borehole samples from B98-13 and B98-12, collected April 27, 1998 Qualitative abundance designated by major (M), minor (X), trace (T)									
Borehole		B98-12			B98-12		B98-12		
Field Number		98184304			98184305		98184306		
Unit - Depth		Fill Unit - 16 ft			Silt Unit - 22 ft		Aquifer Unit - 26 ft		
Laboratory Number (last two digits of series 98182350-98182385)		83	68	69	72	73	76	77	
Size Fraction *		gravel*	f sand	silt/clay	f sand	silt/clay	f sand	silt/clay	
Material **		wh rim	bulk	bulk	bulk	bulk	bulk	bulk	
PHASE	GENERIC FORMULA								
SILICA									
Quartz	SiO ₂	M	M	M	M	M	M	M	
Cristobalite	SiO ₂	X	T	T	T	T			
SILICATE									
Feldspar	(K,Na,Ca)Al(Al,Si) ₃ O ₈	M	M	M	M	M	M	M	
Pyroxene	(Ca,Mg,Fe) ₂ (Si,Al) ₂ O ₆			T	T	T	T	T	
Amphibole ***	(Ca,Na) ₂ (Mg,Fe,Al) ₅ (Si,Al) ₈ O ₂₂ (OH) ₂		T	T	X	T	T	T	
Mica ***	K(Al,Mg,Fe) ₂₋₃ (Si,Al) ₄ O ₁₀ (OH,F) ₂		T	T	X	T	X	X	
CLAY MINERALS									
Illite	(K,Na,Ca)(Mg,Fe,Al) ₂₋₃ (Al,Si) ₄ O ₁₀ (OH) ₂			T		T		X	
Smectite	Ca _{0.5} (Mg,Fe) ₃ (Si,Al) ₄ O ₁₀ (OH) ₂ ·4H ₂ O	T		T	X	X	X	X	
Chlorite ***	(Mg,Fe) ₆ AlSi ₃ O ₁₀ (OH) ₈		T	T	X	X	X	X	
Kaolinite ***	Al ₂ Si ₂ O ₅ (OH) ₄							T	
OXIDES									
Magnetite ***	Fe ₃ O ₄		T	T	T	T	T	T	
CARBONATES									
Calcite	CaCO ₃	M	T	X	T	T	T	T	
Aragonite	CaCO ₃	X							
Vaterite	CaCO ₃	T							
OTHER									
Amorphous				T		T		T	
EXPLANATION AND PHASE NOTES									
* Size Fractions: silt/clay (<0.07 mm), f sand (0.07-0.5 mm), c sand (0.5-2 mm), gravel (>2 mm), gravel*-cut pebbles (>10 mm).									
** Material: wh-white, bl-black, or-orange coatings or alteration rims.									
*** Amphibole primarily hornblende.									
*** Mica primarily muscovite; may include some biotite.									
*** Chlorite may include some kaolinite									
*** Magnetite may include maghemite and chromite.									

ATTACHMENTS

Attachment 1. Detailed list of phases identified by x-ray diffraction.

Attachment 2. Annotated diffractograms.

Attachment 3. Notes on microscopic observations.

Attachment 1. Detailed List of Phases Identified by X-ray Diffraction.

Information on Phase List (Table A1):

- a. Field and laboratory numbers.
- b. Specimen preparation - size fraction and material type.
- c. Phase and card number used for peak match with two-theta positions and relative intensities from the ICDD PDF-2 file (International Centre for Diffraction Data, Powder Diffraction File);
- d. Qualitative abundance designated as major (>20%), minor (5-20%), and trace (<5%) based on peak area or height.

Table A1. List of phases identified by x-ray diffraction.

Frontier Hard Chrome Mineralogy - phases identified by x-ray diffraction.													
Qualitative abundance designated by major (M), minor (X), trace (T).													
Borehole - Unit - Depth		B98-13 - Fill Unit - 16 ft											
Field Sample		98184301											
Laboratory Number	last two digits of series 98182350-98182385		79	50	52	53	53		54	55	55	55	56
Size Fraction	sc-silt/clay, fs/cs-fine/coarse sand, g-gravel, cp-cut pebble		cp	g	fs	sc	sc		g	cs	cs	cs	fs
Material	wh/bl/or ct/rim-white, bl-black, or-orange coatings or rims		wh ct	bl ct	bulk	bulk	sed		wh ct	bl rim	or ct	wh ct	bulk
Material	sed-suspended sediment, mag-magnetic separate												
Speciman Mount			plate	plate	box	b-v	filter 1		plate	plate	plate	plate	box
run			fc79r1	fc50r	fc52	fc53	fc53f		fc54r	fc55bl	fc55or	fc55wh	fc56
pattern	c-coded p-printed r-run		cpr	cpr	cpr	pr	pr		cpr	cpr	cpr	cpr	cpr
PHASE	ICDD	GENERIC FORMULA											
SILICA													
Quartz	46-1045	SiO ₂	X	M	M	M	X		X	T	M	X	M
Cristobalite	39-1425	SiO ₂	X			T				T		T	T
SILICATE													
Feldspar		(K,Na,Ca)Al(Al,Si) ₃ O ₈	M	M	M	M	X		X	M	X	M	M
Anorthite ord	41-1486	CaAl ₂ Si ₂ O ₈											
Anorthite Na ord	20-0528	(Ca,Na)(Al,Si) ₂ Si ₂ O ₈											M
Anorthite Na dis	41-1481	(Ca,Na)(Al,Si) ₄ O ₈								M			
Anorthite Na int	18-1202	(Ca,Na)(Al,Si) ₄ O ₈		M								M	
Albite Ca ord	41-1480	(Na,Ca)Al(Si,Al) ₃ O ₈			M								M
Albite ord	09-0466	NaAlSi ₃ O ₈											
Albite ord	19-1184	NaAlSi ₃ O ₈											
Albite dis	10-0393	NaAlSi ₃ O ₈	M							M			
Orthoclase	31-0966	KAlSi ₃ O ₈											T
Microcline int	19-0932	KAlSi ₃ O ₈											T
Pyroxene		(Ca,Mg,Fe) ₂ (Si,Al) ₂ O ₆		T	T	T				X	T	T	T
Augite	24-0201	Ca(Fe,Mg)Si ₂ O ₆								X			T
Amphibole *		(Ca,Na) ₂ (Mg,Fe,Al) ₅ (Si,Al) ₈ O ₂₂ (OH) ₂			T	T							X
Hastingsite Mg	20-0469	(Ca,Na) ₂ (Fe,Al) ₅ (Si,Al) ₈ O ₂₂ (OH) ₂											X
Magnesiohorneblende	20-0481	(Ca,Na) ₂ (Mg,Fe,Al) ₅ (Si,Al) ₈ O ₂₂ (OH) ₂											
MICA													
Muscovite **		K(Al,Mg,Fe) ₂₋₃ (Si,Al) ₄ O ₁₀ (OH,F) ₂			T	T					T		
Muscovite 2M1	06-0263	KAl ₂ (Si ₃ Al)O ₁₀ (OH,F) ₂											X
Biotite **		K(Mg,Fe) ₃ (Si ₃ Al) ₄ O ₁₀ (OH,F) ₂											T
Biotite 1M	24-0867	KMg ₃ (Si ₃ Al)O ₁₀ (OH) ₂											
Phlogopite 1M	16-0344	KMg ₃ (Si ₃ Al)O ₁₀ F ₂											T
CLAY MINERALS													
Illite **		(K,Na,Ca)(Mg,Fe,Al) ₂₋₃ (Al,Si) ₄ O ₁₀ (OH) ₂					X						
Illite 2M1	26-0911	(K,H3O)Al ₂ Si ₃ AlO ₁₀ (OH) ₂											
Smectite	13-0305	Ca _{0.5} (Mg,Fe) ₃ (Si,Al) ₄ O ₁₀ (OH) ₂ ·4H ₂ O	T	T		T	X	X	X	T	T	T	X
Chlorite ***		(Mg,Fe) ₆ AlSi ₃ O ₁₀ (OH) ₃			T	T	T				T		X
Clinochlore 1Mlb-2	46-1323	(Mg,Al,Fe) ₆ (Si,Al) ₄ O ₁₀ (OH) ₃											X
Clinochlore 1Mlb	12-0242	(Mg,Fe) ₆ (Si,Al) ₄ O ₁₀ (OH) ₃											
Kaolinite ***	14-0164	Al ₂ Si ₂ O ₅ (OH) ₄											
Amorphous							M						
OXIDES													
Magnetite ****	19-0629	Fe ₃ O ₄		T	T	T				T			T
CARBONATES													
Calcite	05-0586	CaCO ₃	M		T	T			M			M	
Calcite, magnesian	43-0697	CaCO ₃											
Aragonite	41-1475	CaCO ₃											
Vatentite	33-0268	CaCO ₃	T									T	
Calcite mg	43-0697	(Ca,Mg)CO ₃											
PHASE NOTES													
* Primarily hornblende.													
** Muscovite may include some biotite; illite assigned to clay-size fraction.													
*** Chlorite may include some kaolinite.													
**** Magnetite may include maghemite and chromite.													

Table A1. List of phases identified by x-ray diffraction.

Frontier Hard Chrome Mineralogy - phases identified by x-ray diffraction. Qualitative abundance designated by major (M), minor (X), trace (T).												
Borehole - Unit - Depth			B98-13 - Silt Unit - 21 ft									
Field Sample			98184302									
Laboratory Number	last two digits of series 98182350-98182385		56	56	56	56	56	56	56	57	57	57
Size Fraction	sc-silt/clay, fs/cs-fine/coarse sand, g-gravel, cp-cut pebble		fs	fs	fs	fs	fs	fs	fs	sc	sc	sc
Material	wh/bl/or cl/rim-white, bl-black, or-orange coatings or rims		mag	mag	mag	mag	mag	mag	mag	bulk	sed	sed
	sed-suspended sediment, mag-magnetic separate											
Speciman Mount			box	box	box	box	box	box	box	box	slide	filter 1
run			fcmf1	fcmf2	fcmp1	fcmp2	fcmp4	fcmp3d	fcmf1	fc57	fc57s	fc57f1
pattern	c-coded p-printed r-run		cpr	cpr	pr	cpr	cpr	cpr	cpr	pr	cpr	pr
PHASE	ICDD	GENERIC FORMULA										
SILICA												
Quartz	46-1045	SiO ₂	X	X	M	M	M	M	M	M	M	X
Cristobalite	39-1425	SiO ₂						T		T		
SILICATE												
Feldspar		(K,Na,Ca)Al(Al,Si) ₃ O ₈	M	M	M	M	M	M	T	M	M	T
Anorthite ord	41-1486	CaAl ₂ Si ₂ O ₈										
Anorthite Na ord	20-0528	(Ca,Na)(Al,Si) ₂ Si ₂ O ₈										
Anorthite Na dis	41-1481	(Ca,Na)(Al,Si) ₄ O ₈				M	M					
Anorthite Na int	18-1202	(Ca,Na)(Al,Si) ₄ O ₈		M								
Albite Ca ord	41-1480	(Na,Ca)Al(Si,Al) ₃ O ₈										
Albite ord	09-0466	NaAlSi ₃ O ₈					M					
Albite ord	19-1184	NaAlSi ₃ O ₈							T			
Albite dis	10-0393	NaAlSi ₃ O ₈										
Orthoclase	31-0966	KAlSi ₃ O ₈							T			
Microcline int	19-0932	KAlSi ₃ O ₈										
Pyroxene		(Ca,Mg,Fe) ₂ (Si,Al) ₂ O ₆	X	X	X	T	T			T		
Augite	24-0201	Ca(Fe,Mg)Si ₂ O ₆	X	X								
Amphibole *		(Ca,Na) ₂ (Mg,Fe,Al) ₅ (Si,Al) ₈ O ₂₂ (OH) ₂					X			T	T	
Hastingsite Mg	20-0469	(Ca,Na) ₂ (Fe,Al) ₅ (Si,Al) ₈ O ₂₂ (OH) ₂										
Magnesiohorneblende	20-0481	(Ca,Na) ₂ 26(Mg,Fe,Al) ₅ (Si,Al) ₈ O ₂₂ (OH) ₂				X						
MICA												
Muscovite **		K(Al,Mg,Fe) ₂₋₃ (Si,Al) ₄ O ₁₀ (OH,F) ₂			X		M	T		X		
Muscovite 2M1	06-0263	KAl ₂ (Si ₃ Al)O ₁₀ (OH,F) ₂				X						
Biotite **		K(Mg,Fe) ₃ (Si ₃ Al) ₄ O ₁₀ (OH,F) ₂	T	T		T	T					
Biotite 1M	24-0867	KMg ₃ (Si ₃ Al)O ₁₀ (OH) ₂					T					
Phlogopite 1M	16-0344	KMg ₃ (Si ₃ Al)O ₁₀ F ₂										
CLAY MINERALS												
Illite **		(K,Na,Ca)(Mg,Fe,Al) ₂₋₃ (Al,Si) ₄ O ₁₀ (OH) ₂									X	X
Illite 2M1	26-0911	(K,H3O)Al ₂ Si ₃ AlO ₁₀ (OH) ₂										
Smectite	13-0305	Ca _{0.5} (Mg,Fe) ₃ (Si,Al) ₄ O ₁₀ (OH) ₂ ·4H ₂ O									X	M
Chlorite ***		(Mg,Fe) ₆ AlSi ₅ O ₁₀ (OH) ₈			X	X	M	T		X	T	T
Clinocllore 1Mlb-2	46-1323	(Mg,Al,Fe) ₆ (Si,Al) ₄ O ₁₀ (OH) ₈										
Clinocllore 1Mlb	12-0242	(Mg,Fe) ₆ (Si,Al) ₄ O ₁₀ (OH) ₈				X						
Kaolinite ***	14-0164	Al ₂ Si ₂ O ₅ (OH) ₄									T	
Amorphous											X	M
OXIDES												
Magnetite ****	19-0629	Fe ₃ O ₄	M	X		T	T			T		
CARBONATES												
Calcite	05-0586	CaCO ₃										
Calcite, magnesian	43-0697	CaCO ₃										
Aragonite	41-1475	CaCO ₃										
Valentite	33-0268	CaCO ₃										
Calcite mg	43-0697	(Ca,Mg)CO ₃										
PHASE NOTES												
* Primarily horneblende.												
** Muscovite may include some biotite; illite assigned to clay-size fraction.												
*** Chlorite may include some kaolinite.												
**** Magnetite may include maghemite and chromite.												

Table A1. List of phases identified by x-ray diffraction.

Frontier Hard Chrome Mineralogy - phases identified by x-ray diffraction.											
Qualitative abundance designated by major (M), minor (X), trace (T)											
Borehole - Unit - Depth		B98-13 - Silt Unit - 21 ft				B98-13 - Aquifer Unit - 25 ft					
Field Sample		98184302 dup				98184303					
Laboratory Number	last two digits of series 98182350-98182385	60	61	61	61	64	65	65	65		
Size Fraction	sc-silt/clay, fs/cs-fine/coarse sand, g-gravel, cp-cut pebble.	fs	sc	sc	sc	fs	sc	sc	sc		
Material	wh/bl/or ct/rim-white, bl-black, or-orange coatings or rims	bulk	bulk	sed	sed	bulk	bulk	sed	sed		
	sed-suspended sediment, mag-magnetic separate										
Speciman Mount		box	box	slide	filter 1	box	box	filter 1	filter 1		
run		fc60	fc61	fc61s	fc61f1	fc64	fc65	fc65f1	fc65f2		
pattern	c-coded p-printed r-run	cpr	pr	cpr	pr	cpr	pr	pr	pr		
PHASE	ICDD	GENERIC FORMULA									
SILICA											
Quartz	46-1045	SiO ₂	M	M	M	M	M	M	M	M	
Cristobalite	39-1425	SiO ₂	T	T			T				
SILICATE											
Feldspar		(K,Na,Ca)Al(Al,Si) ₃ O ₈	M	M	M	M	M	M	M	M	
Anorthite ord	41-1486	CaAl ₂ Si ₂ O ₈									
Anorthite Na ord	20-0528	(Ca,Na)(Al,Si) ₂ Si ₂ O ₈									
Anorthite Na dis	41-1481	(Ca,Na)(Al,Si) ₄ O ₈									
Anorthite Na int	18-1202	(Ca,Na)(Al,Si) ₄ O ₈					X				
Albite Ca ord	41-1480	(Na,Ca)Al(Si,Al) ₃ O ₈									
Albite ord	09-0466	NaAlSi ₃ O ₈					M				
Albite ord	19-1184	NaAlSi ₃ O ₈									
Albite dis	10-0393	NaAlSi ₃ O ₈	M								
Orthoclase	31-0966	KAlSi ₃ O ₈									
Microcline int	19-0932	KAlSi ₃ O ₈									
Pyroxene		(Ca,Mg,Fe) ₂ (Si,Al) ₂ O ₆	T	T				T			
Augite	24-0201	Ca(Fe,Mg)Si ₂ O ₆									
Amphibole *		(Ca,Na) ₂ (Mg,Fe,Al) ₅ (Si,Al) ₈ O ₂₂ (OH) ₂	T	T	T		T	T			
Hastingsite Mg	20-0469	(Ca,Na) ₂ (Fe,Al) ₅ (Si,Al) ₈ O ₂₂ (OH) ₂									
Magnesianhornblende	20-0481	(Ca,Na) ₂ 26(Mg,Fe,Al) ₅ 15(Si,Al) ₈ O ₂₂ (OH) ₂									
MICA											
Muscovite **		K(Al,Mg,Fe) ₂₋₃ (Si,Al) ₄ O ₁₀ (OH,F) ₂	X	X			X	X			
Muscovite 2M1	06-0263	KAl ₂ (Si ₃ Al)O ₁₀ (OH,F) ₂									
Biotite **		K(Mg,Fe) ₃ (Si ₃ Al) ₄ O ₁₀ (OH,F) ₂					T				
Biotite 1M	24-0867	KMg ₃ (Si ₃ Al)O ₁₀ (OH) ₂									
Phlogopite 1M	16-0344	KMg ₃ (Si ₃ Al)O ₁₀ F ₂									
CLAY MINERALS											
Illite **		(K,Na,Ca)(Mg,Fe,Al) ₂₋₃ (Al,Si) ₄ O ₁₀ (OH) ₂			X	T			X	X	
Illite 2M1	26-0911	(K,H3O)Al ₂ Si ₃ AlO ₁₀ (OH) ₂									
Smectite	13-0305	Ca _{0.5} (Mg,Fe) ₃ (Si,Al) ₄ O ₁₀ (OH) ₂ ·4H ₂ O	X	T	X	T	X	X	M	X	
Chlorite ***		(Mg,Fe) ₆ AlSi ₃ O ₁₀ (OH) ₈	X	X	T	T	X	X	T	T	
Clinochlore 1Mlb-2	46-1323	(Mg,Al,Fe) ₆ (Si,Al) ₄ O ₁₀ (OH) ₈	X								
Clinochlore 1Mlb	12-0242	(Mg,Fe) ₆ (Si,Al) ₄ O ₁₀ (OH) ₈									
Kaolinite ***	14-0164	Al ₂ Si ₂ O ₅ (OH) ₄		T	T						
Amorphous				X	X	X		X	X	T	
OXIDES											
Magnetite ****	19-0629	Fe ₃ O ₄	T	T			T	T			
CARBONATES											
Calcite	05-0586	CaCO ₃	T								
Calcite, magnesian	43-0697	CaCO ₃									
Aragonite	41-1475	CaCO ₃									
Vaterite	33-0268	CaCO ₃									
Calcite mg	43-0697	(Ca,Mg)CO ₃	T				X	T			
PHASE NOTES											
* Primarily hornblende.											
** Muscovite may include some biotite; illite assigned to clay-size fraction.											
*** Chlorite may include some kaolinite.											
**** Magnetite may include maghemite and chromite.											

Table A1. List of phases identified by x-ray diffraction.

Frontier Hard Chrome Mineralogy - phases identified by x-ray diffraction. Qualitative abundance designated by major (M), minor (X), trace (T).													
Borehole - Unit - Depth		B98-12 - Fill Unit - 16 ft				B98-12 - Silt Unit - 22 ft			B98-12 - Aquifer Unit - 26 ft				
Field Sample		98184304				98184305			98184306				
Laboratory Number		last two digits of series 98182350-98182385				83	68	69	69	72	73	73	
Size Fraction		sc-silt/clay, fs/cs-fine/coarse sand, g-gravel, cp-cut pebble				cp	fs	sc	sc	fs	sc	sc	
Material		wh/bl/or ct/rim-white, bl-black, or-orange coatings or rims sed-suspended sediment, mag-magnetic separate				wh ct	bulk	bulk	sed	bulk	bulk	sed	
Speciman Mount		box				box	box	filter 2		box	box	filter 1	
run		fc83r				fc68	fc69	fc69f2		fc72	fc73	fc73f1	
pattern		c-coded p-printed r-run				cpr	cpr	pr	cpr	cpr	pr	cpr	
PHASE		ICDD	GENERIC FORMULA										
SILICA													
Quartz	46-1045	SiO ₂	M	M	M	X			M	M	M		
Cristobalite	39-1425	SiO ₂	X	T	T				T	T			
SILICATE													
Feldspar		(K,Na,Ca)Al(Al,Si) ₃ O ₈	M	M	M	M			M	M	M		
Anorthite ord	41-1486	CaAl ₂ Si ₂ O ₈		X									
Anorthite Na ord	20-0528	(Ca,Na)(Al,Si) ₂ Si ₂ O ₈											
Anorthite Na dis	41-1481	(Ca,Na)(Al,Si) ₄ O ₈		M									
Anorthite Na int	18-1202	(Ca,Na)(Al,Si) ₄ O ₈		M					X				
Albite Ca ord	41-1480	(Na,Ca)Al(Si,Al) ₃ O ₈							X				
Albite ord	09-0466	NaAlSi ₃ O ₈											
Albite ord	19-1184	NaAlSi ₃ O ₈											
Albite dis	10-0393	NaAlSi ₃ O ₈		X					X				
Orthoclase	31-0966	KAlSi ₃ O ₈											
Microcline int	19-0932	KAlSi ₃ O ₈							T				
Pyroxene		(Ca,Mg,Fe) ₂ (Si,Al) ₂ O ₆			T				T	T			
Augite	24-0201	Ca(Fe,Mg)Si ₂ O ₆											
Amphibole *		(Ca,Na) ₂ (Mg,Fe,Al) ₅ (Si,Al) ₈ O ₂₂ (OH) ₂		T	T				X	T			
Hastingsite Mg	20-0469	(Ca,Na) ₂ (Fe,Al) ₅ (Si,Al) ₈ O ₂₂ (OH) ₂											
Magnesianhornblende	20-0481	(Ca,Na) ₂ (Mg,Fe,Al) ₅ (Si,Al) ₈ O ₂₂ (OH) ₂											
MICA													
Muscovite **		K(Al,Mg,Fe) ₂₋₃ (Si,Al) ₄ O ₁₀ (OH,F) ₂		T	T				X	T		X	X
Muscovite 2M1	06-0263	KAl ₂ (Si ₃ Al)O ₁₀ (OH,F) ₂										X	
Biotite **		K(Mg,Fe) ₃ (Si ₃ Al) ₄ O ₁₀ (OH,F) ₂											
Biotite 1M	24-0867	KMg ₃ (Si ₃ Al)O ₁₀ (OH) ₂											
Phlogopite 1M	16-0344	KMg ₃ (Si ₃ Al)O ₁₀ F ₂										X	
CLAY MINERALS													
Illite **		(K,Na,Ca)(Mg,Fe,Al) ₂₋₃ (Al,Si) ₄ O ₁₀ (OH) ₂				X						X	T
Illite 2M1	26-0911	(K,H3O)Al ₂ Si ₃ AlO ₁₀ (OH) ₂											
Smectite	13-0305	Ca _{0.5} (Mg,Fe) ₃ (Si,Al) ₄ O ₁₀ (OH) ₂ ·4H ₂ O	T		T	X			X	X	M	X	M
Chlorite ***		(Mg,Fe) ₃ AlSi ₃ O ₁₀ (OH) ₈		T	T	T			X	X	T	X	
Clinocllore 1MIIb-2	46-1323	(Mg,Al,Fe) ₆ (Si,Al) ₄ O ₁₀ (OH) ₈											
Clinocllore 1MIIb	12-0242	(Mg,Fe) ₆ (Si,Al) ₄ O ₁₀ (OH) ₈										T	
Kaolinite ***	14-0164	Al ₂ Si ₂ O ₅ (OH) ₄										T	X
Amorphous					T	M			T	X		T	X
OXIDES													
Magnetite ****	19-0629	Fe ₃ O ₄		T	T				T	T		T	T
CARBONATES													
Calcite	05-0586	CaCO ₃	M	T	X	M			T	X		T	
Calcite, magnesian	43-0697	CaCO ₃											
Aragonite	41-1475	CaCO ₃	X										
Vaterite	33-0268	CaCO ₃	T										
Calcite mg	43-0697	(Ca,Mg)CO ₃		T								T	
PHASE NOTES													
* Primarily hornblende.													
** Muscovite may include some biotite; illite assigned to clay-size fraction.													
*** Chlorite may include some kaolinite.													
**** Magnetite may include maghemite and chromite.													

Attachment 2. Annotated Diffractograms.

Key to mineral designations on annotated diffractograms. Numerical values noted on diffractograms are structural d-spacings; circled d-spacings denote diagnostic peaks used for abundance estimates.

SILICATES

Silica

QZ	quartz	SiO_2
CR	cristobalite	SiO_2

Other Silicates

FS	feldspar	$(\text{K,Na,Ca})\text{Al}(\text{Al,Si})_3\text{O}_8$
PX	pyroxene	$(\text{Ca,Mg,Fe})_2(\text{Si,Al})_2\text{O}_6$
AM	amphibole	$(\text{Na,Ca})_2(\text{Mg,Fe})_5\text{Si}_8\text{O}_{22}(\text{OH})_2$
MI	mica	$\text{K}(\text{Al,Mg,Fe})_{2-3}(\text{Al,Si})_4\text{O}_{10}(\text{OH,F})_2$

Clay Minerals

IL	illite	$(\text{K,Na,Ca})(\text{Mg,Fe,Al})_{2-3}(\text{Al,Si})_4\text{O}_{10}(\text{OH})_2$
SM	smectite	$\text{Ca}_{0.5}(\text{Mg,Fe})_3(\text{Si,Al})_4\text{O}_{10}\text{O}(\text{OH})_2 \cdot 4\text{H}_2\text{O}$
CH	chlorite	$(\text{Mg,Fe})_6\text{AlSi}_3\text{O}_{10}(\text{OH})_8$
KA	kaolinite	$\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$

OXIDES

MT	magnetite	Fe_3O_4
MH	maghemite	Fe_2O_3
CT	chromite	FeCr_2O_4

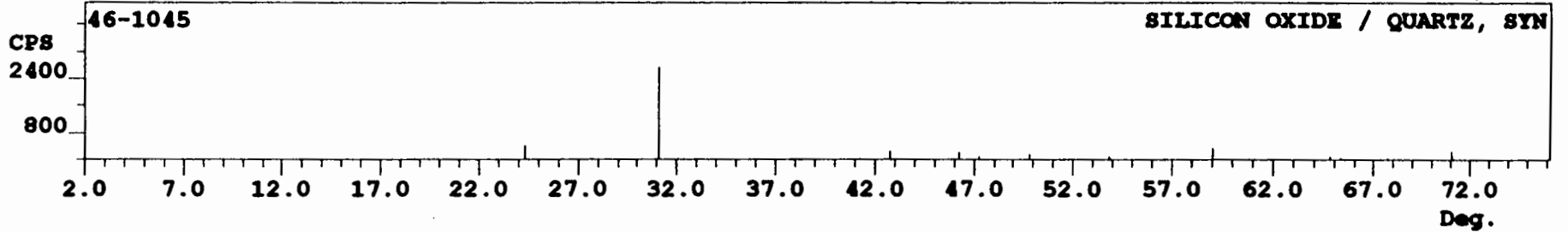
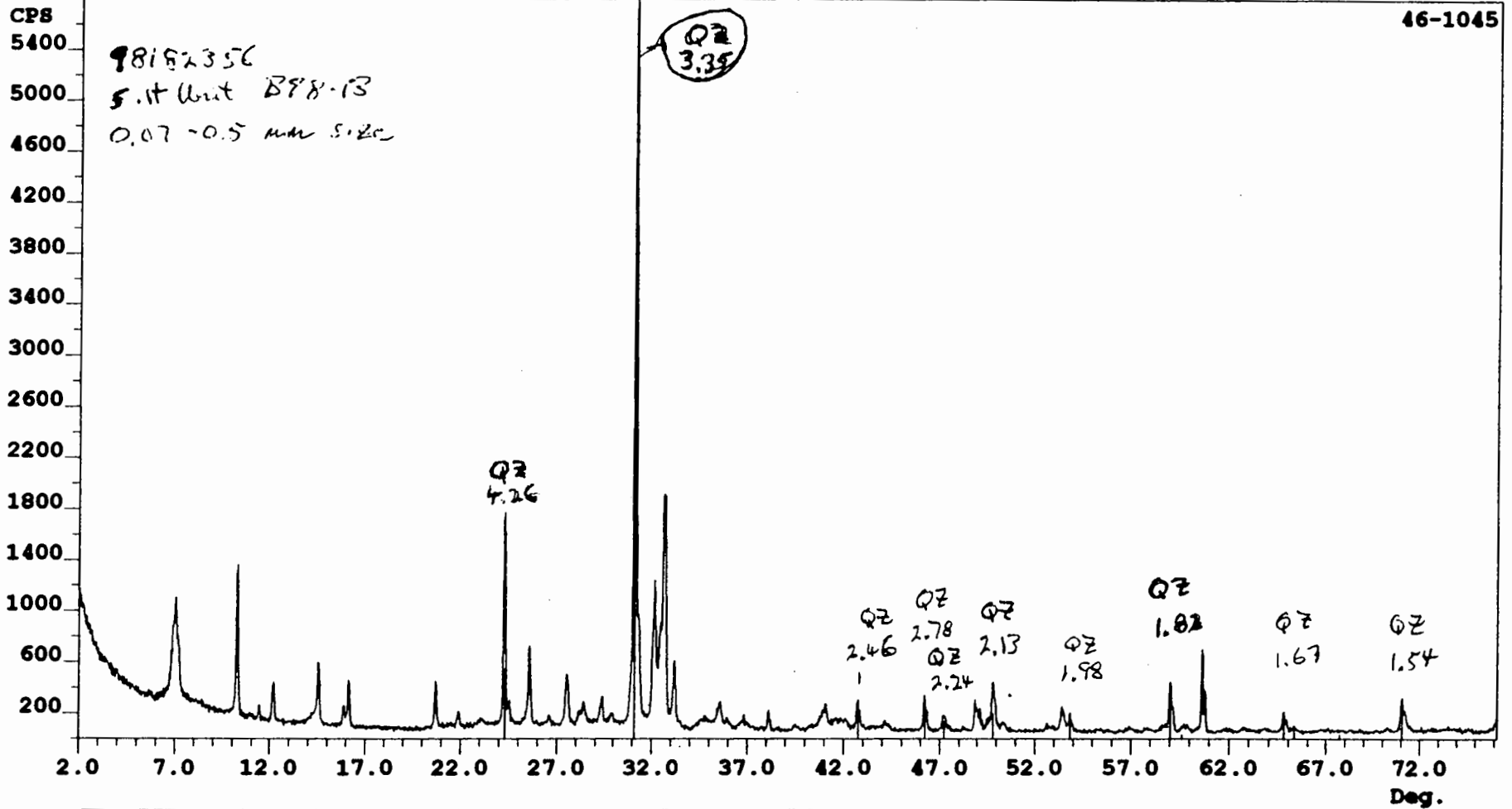
CARBONATES

CA	calcite	CaCO_3
AR	aragonite	CaCO_3
VT	vaterite	CaCO_3

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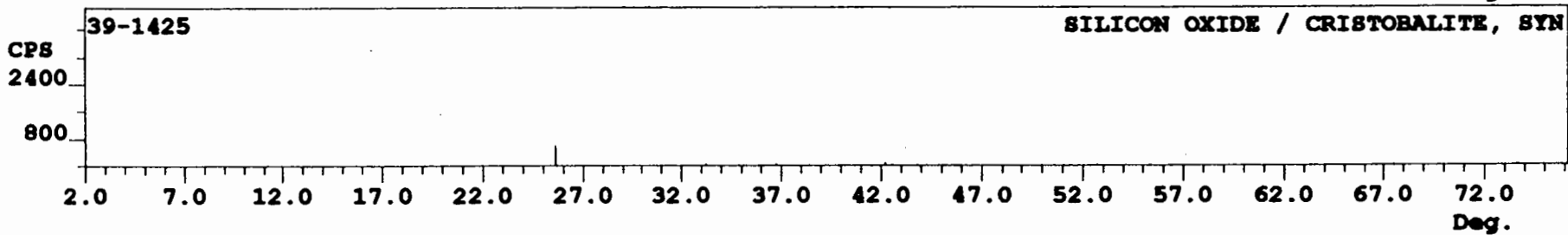
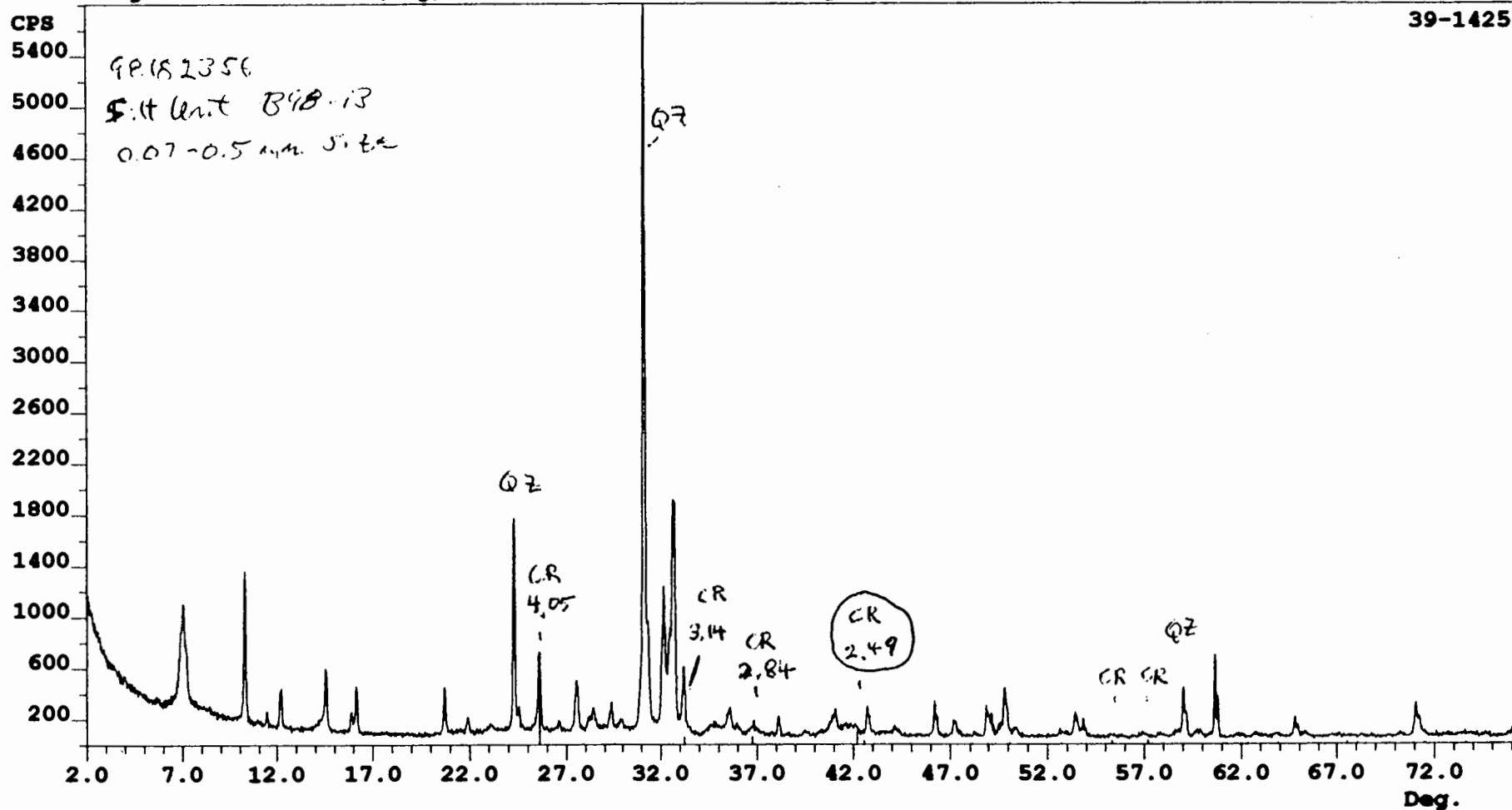
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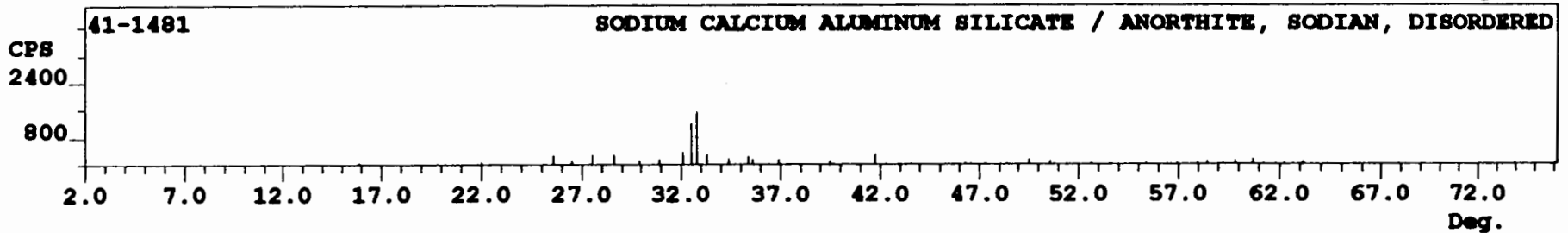
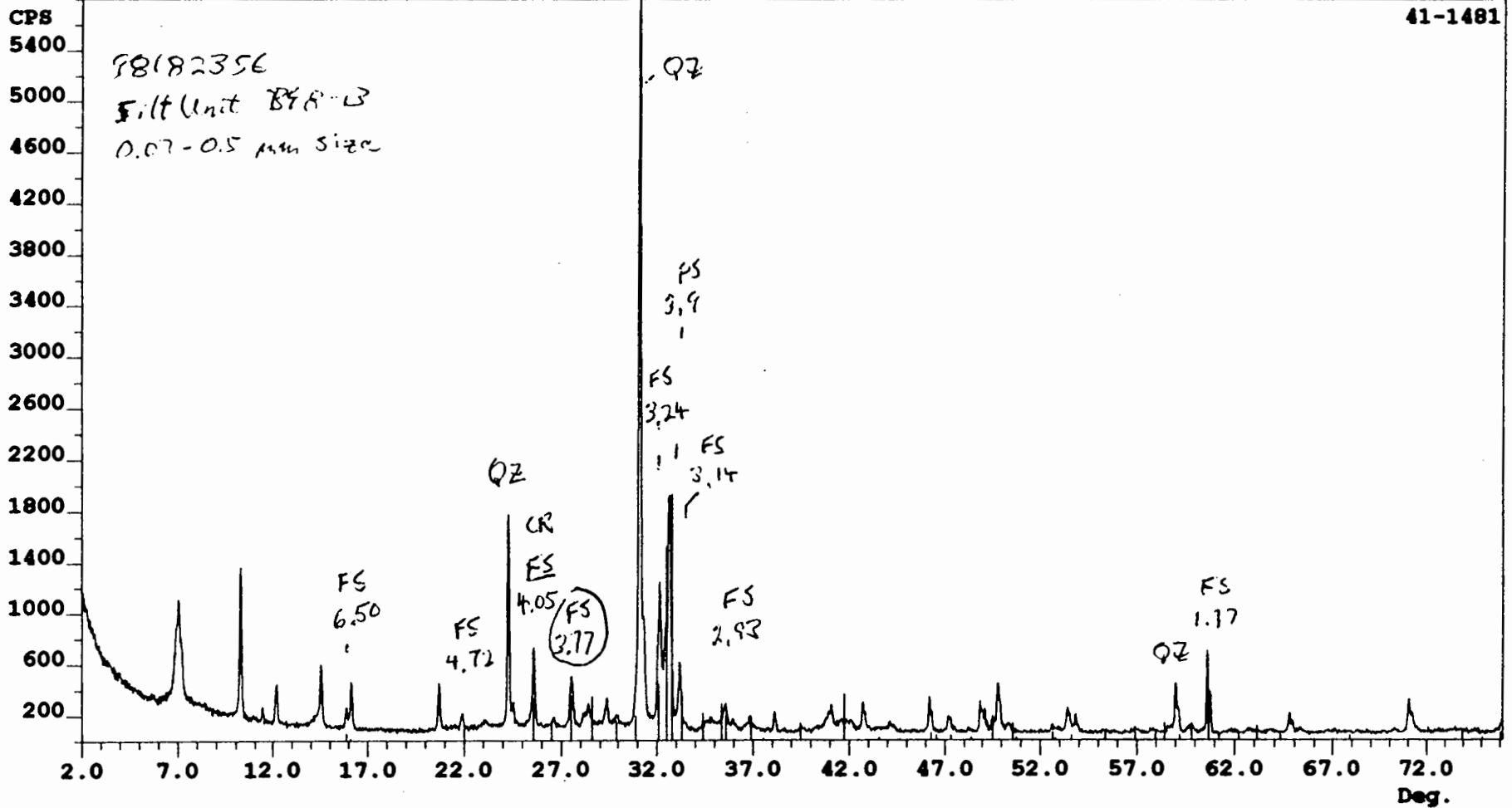
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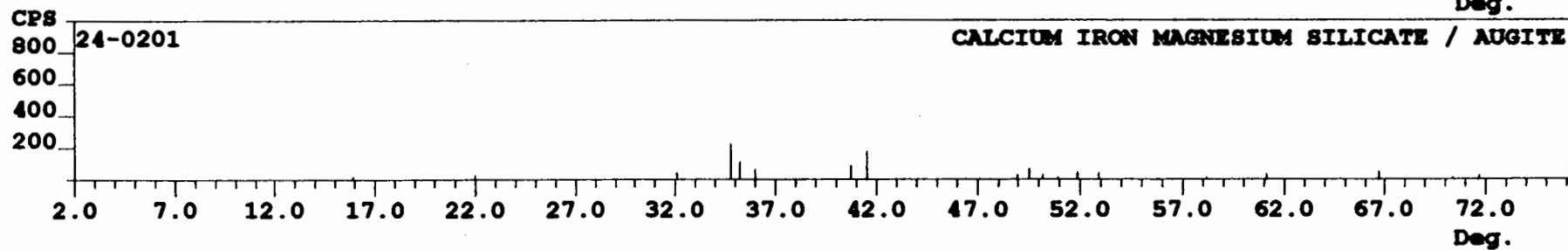
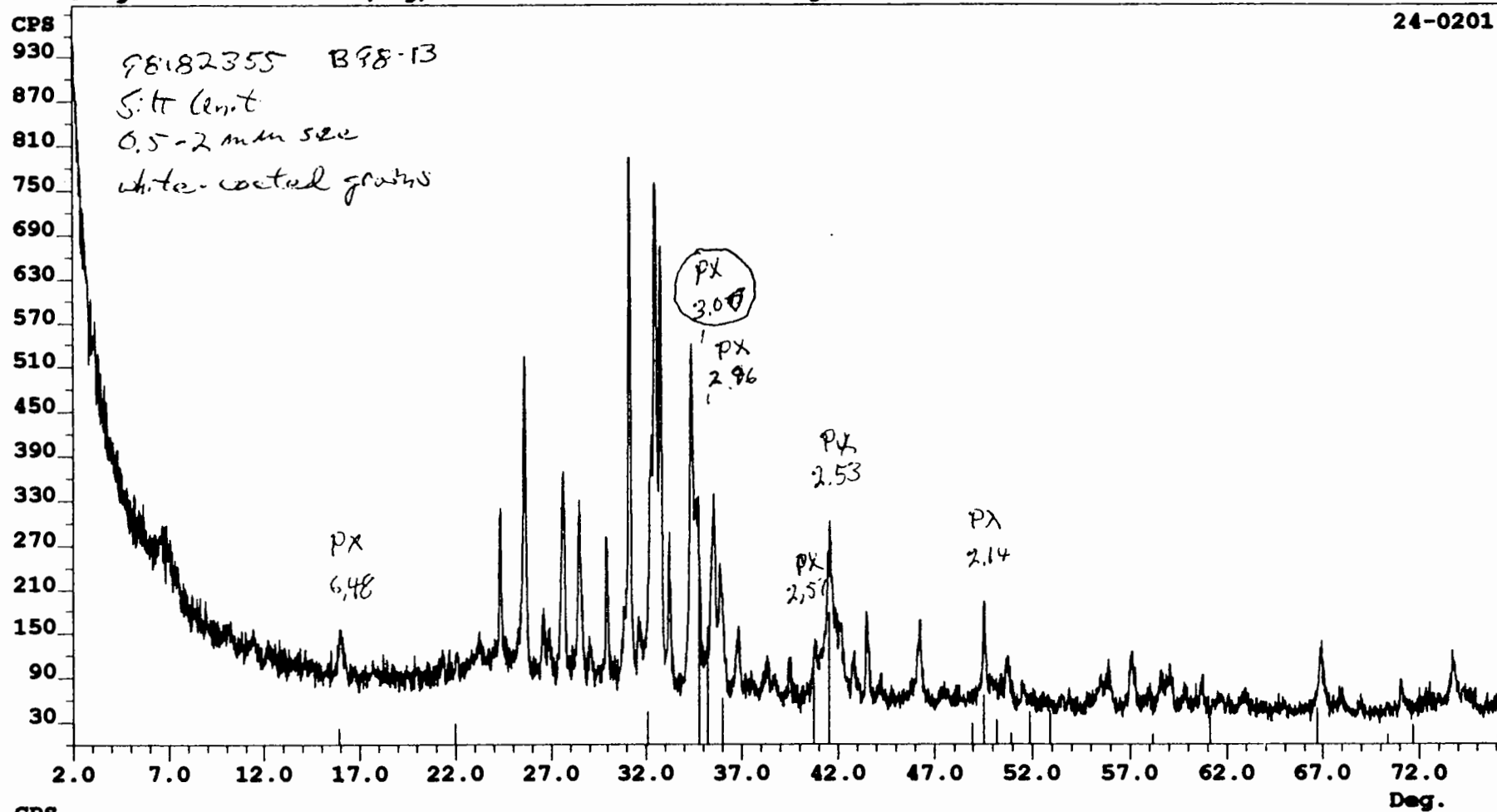
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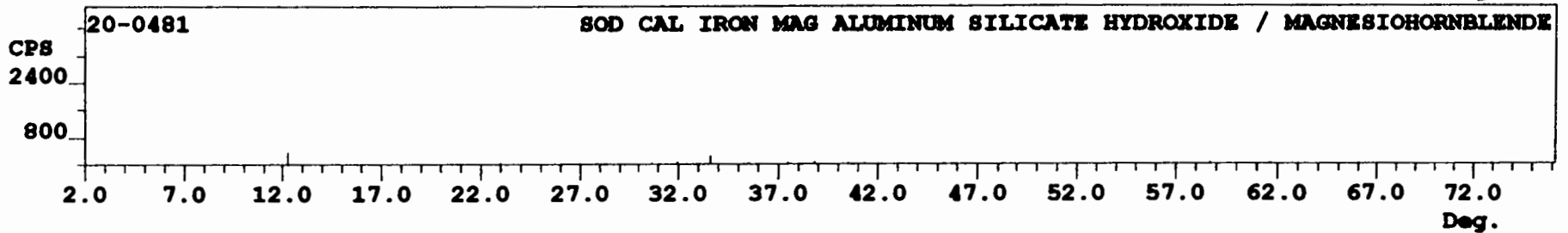
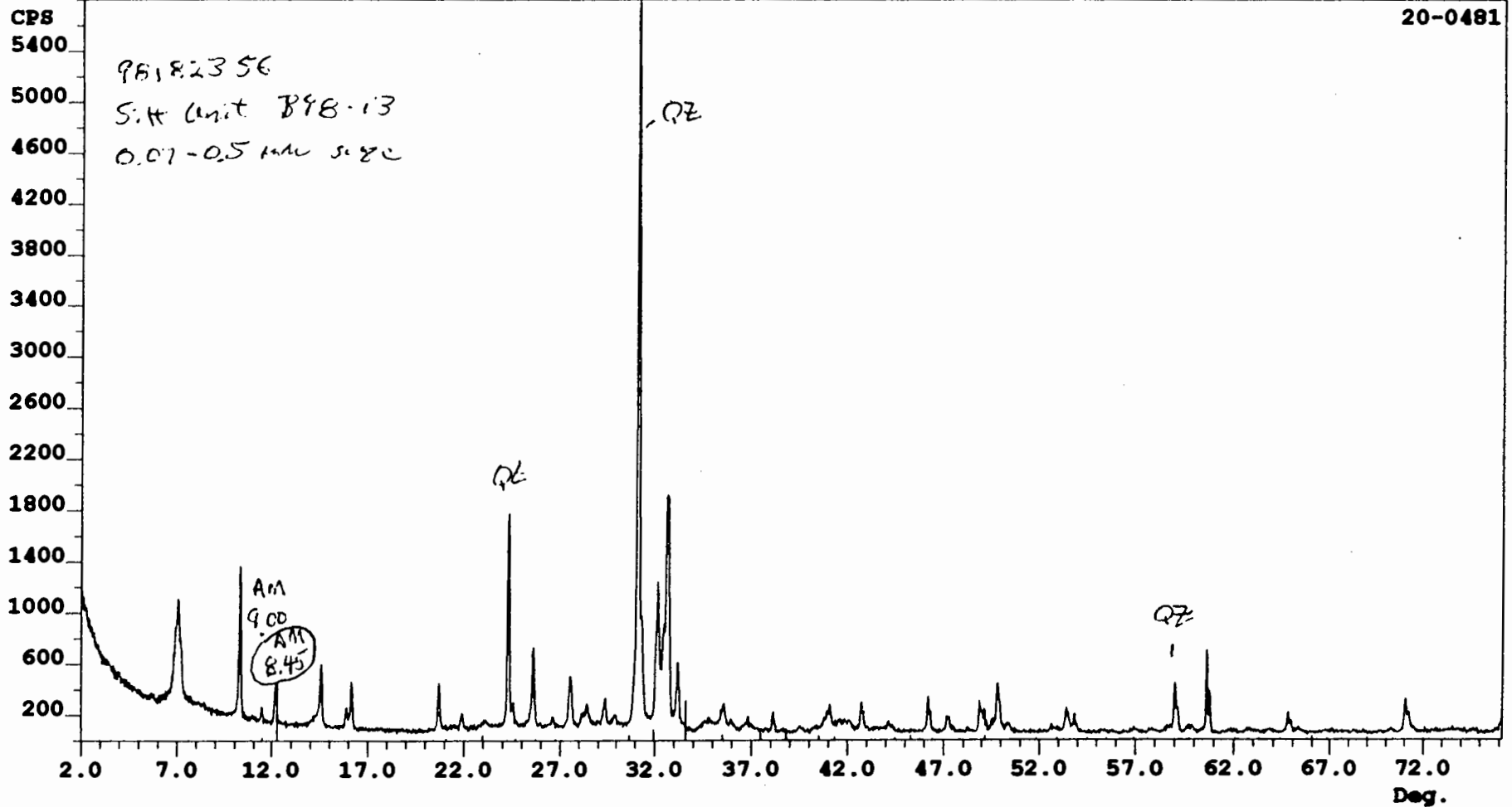
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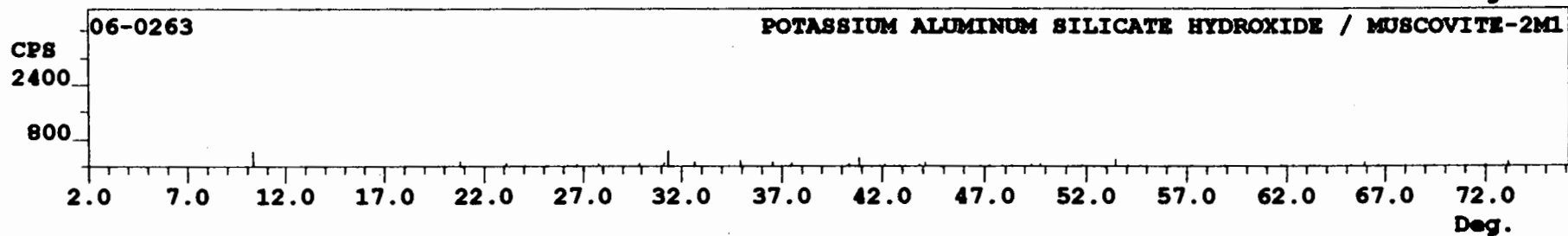
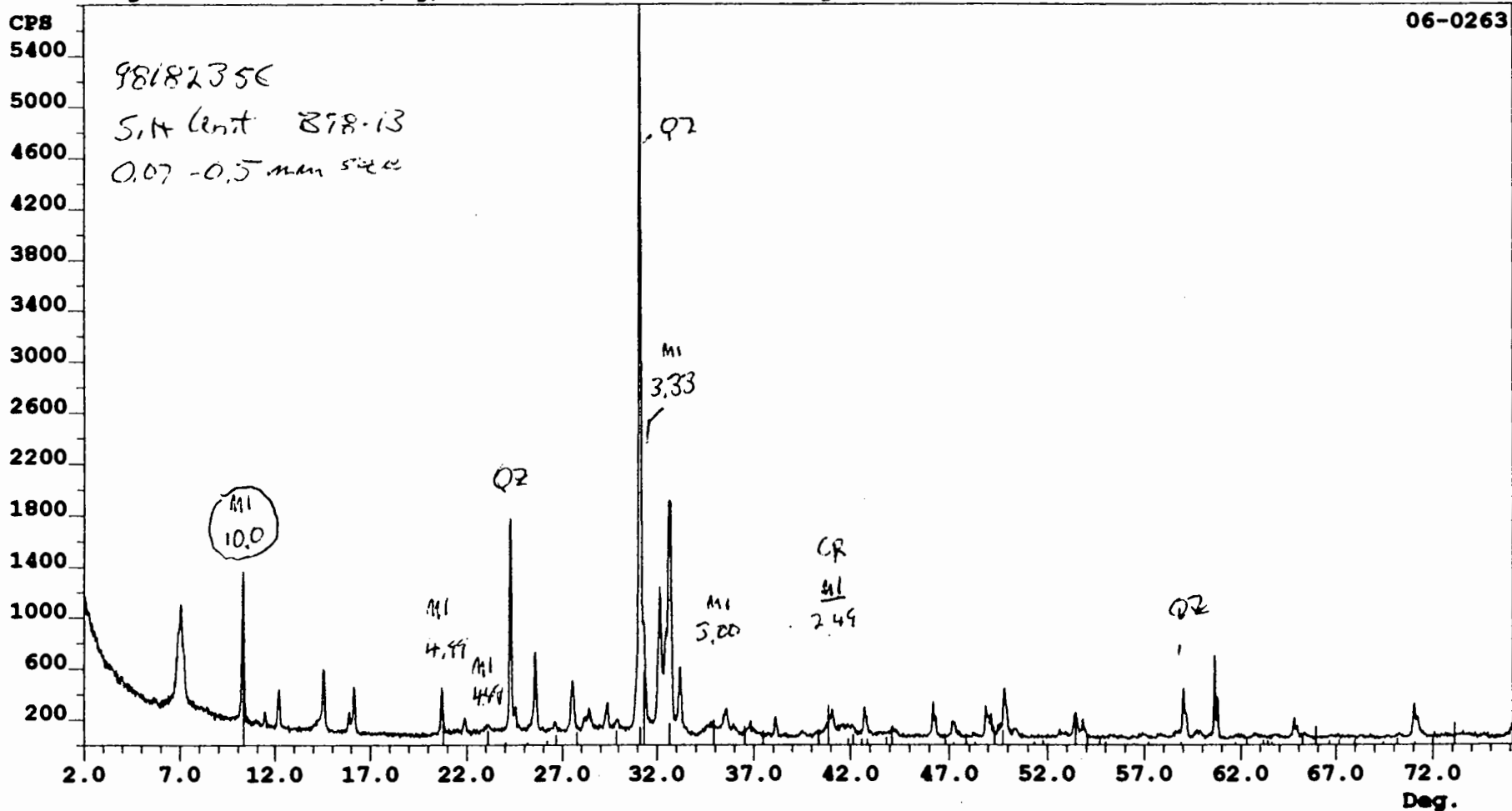


D-5

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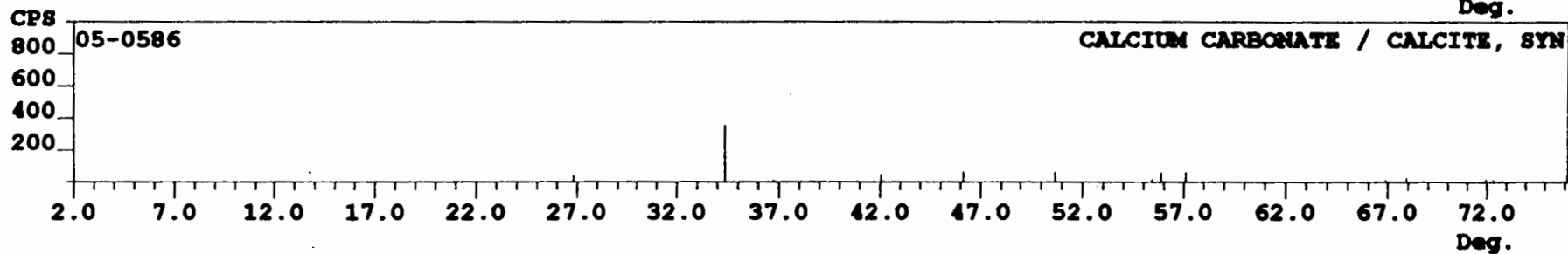
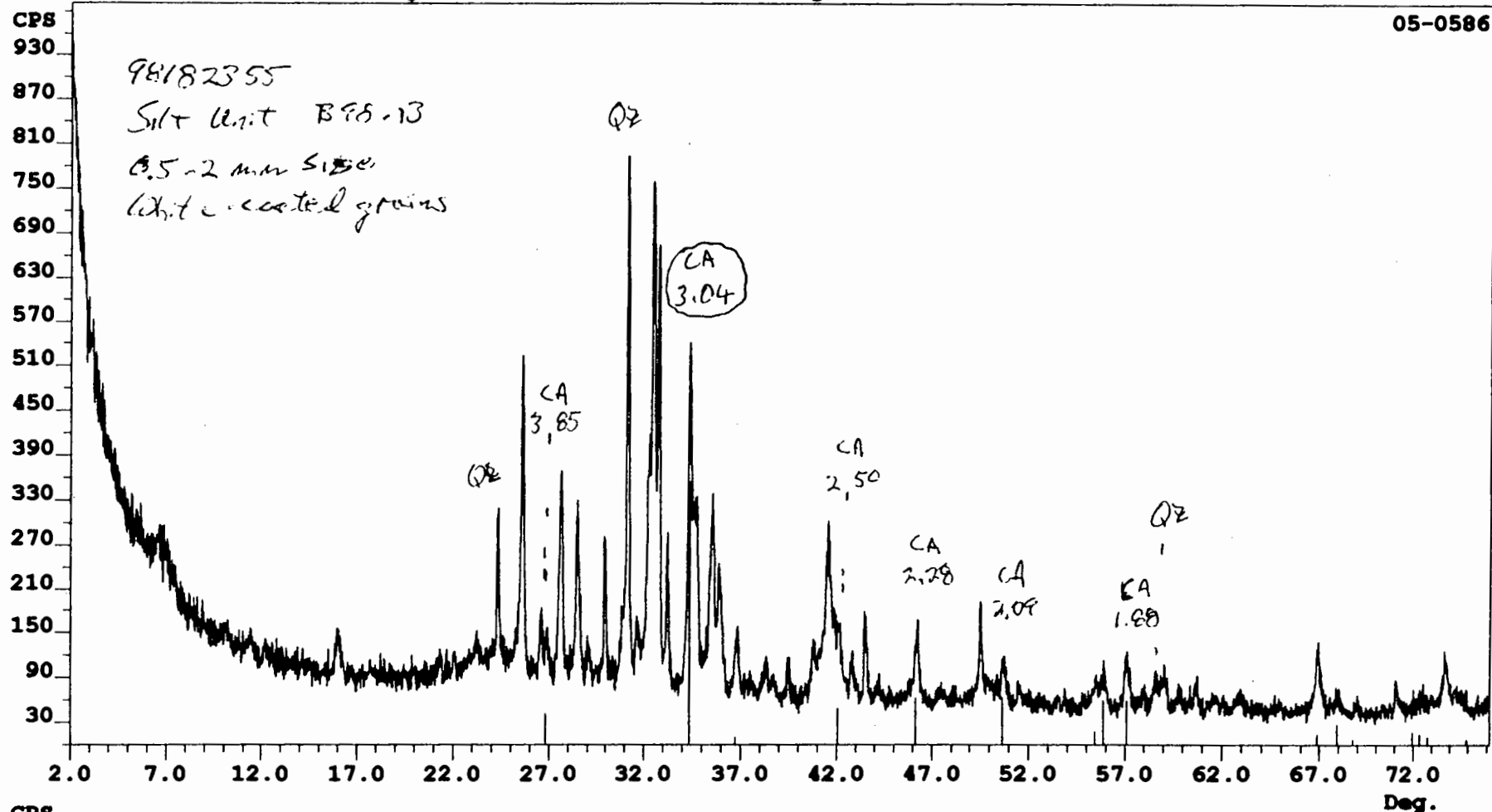
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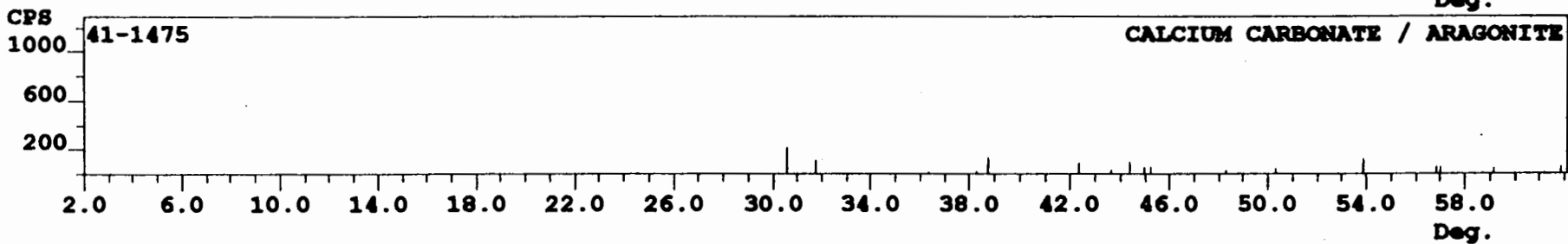
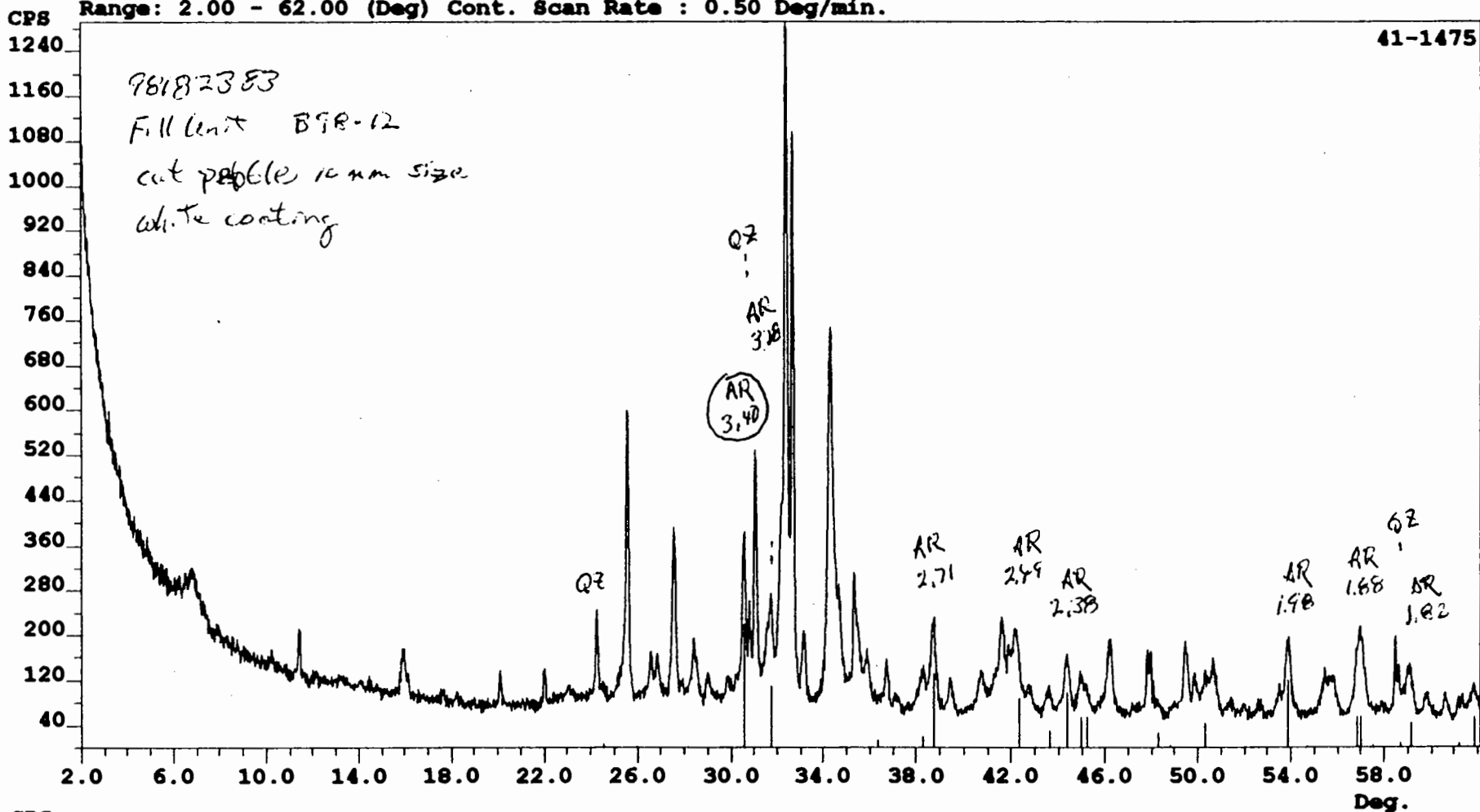


D-7

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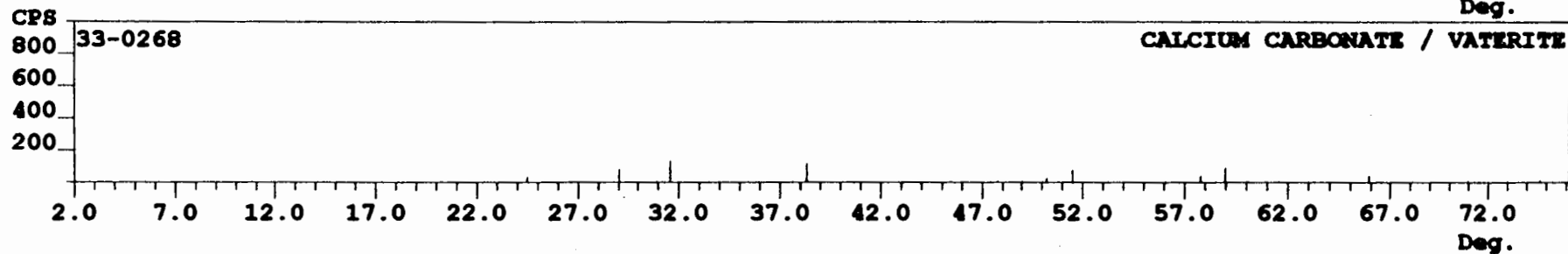
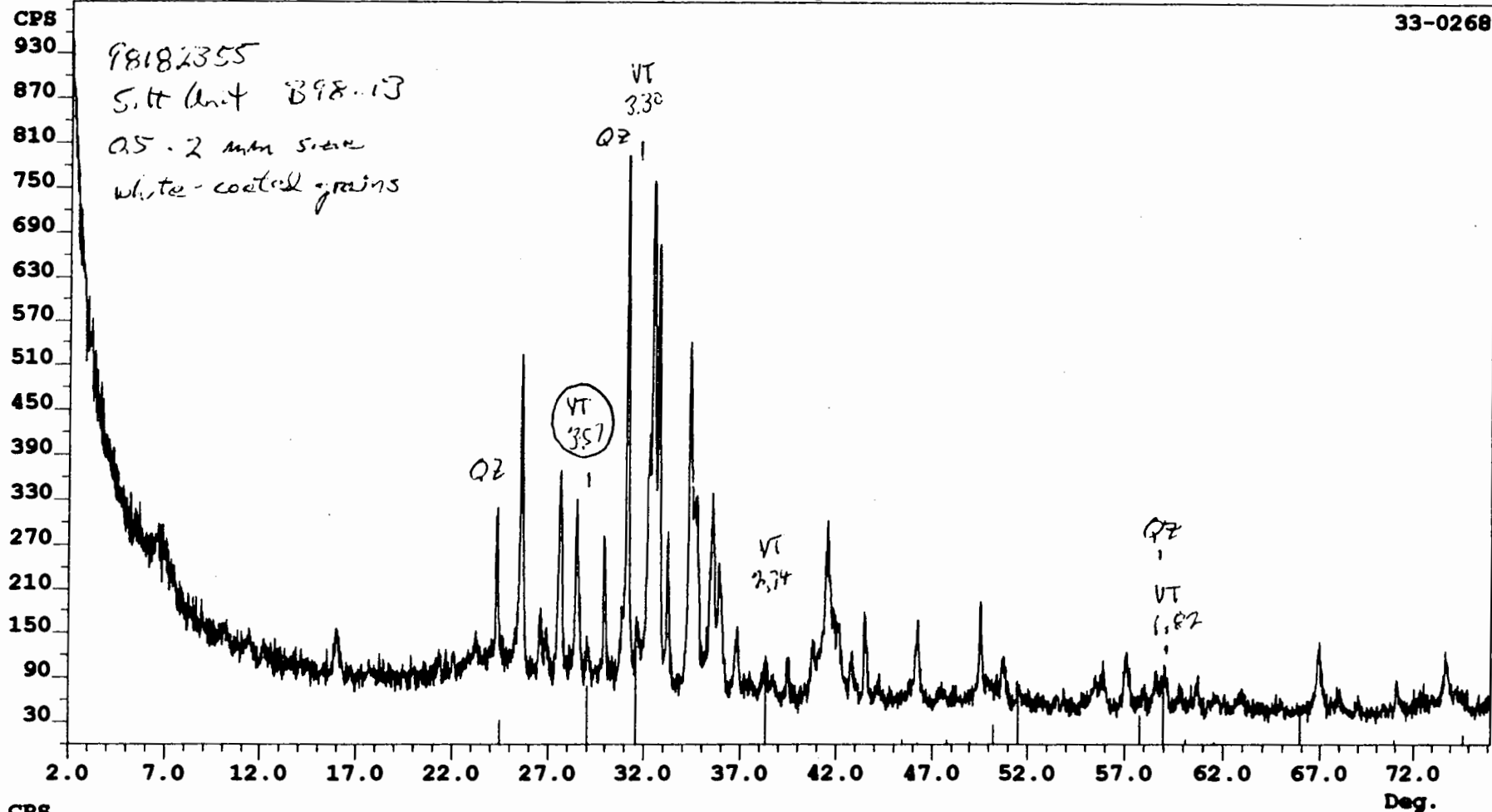


D-8

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Range: 2.00 - 76.00 (Deg) Cont. Scan Rate : 1.00 Deg/min.

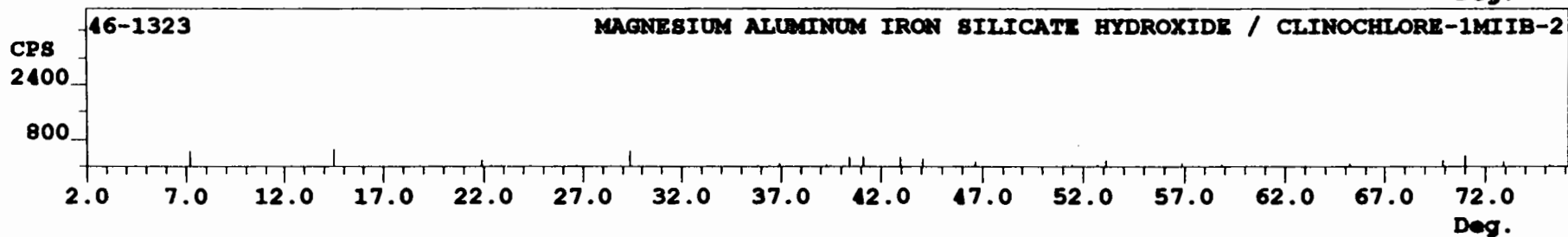
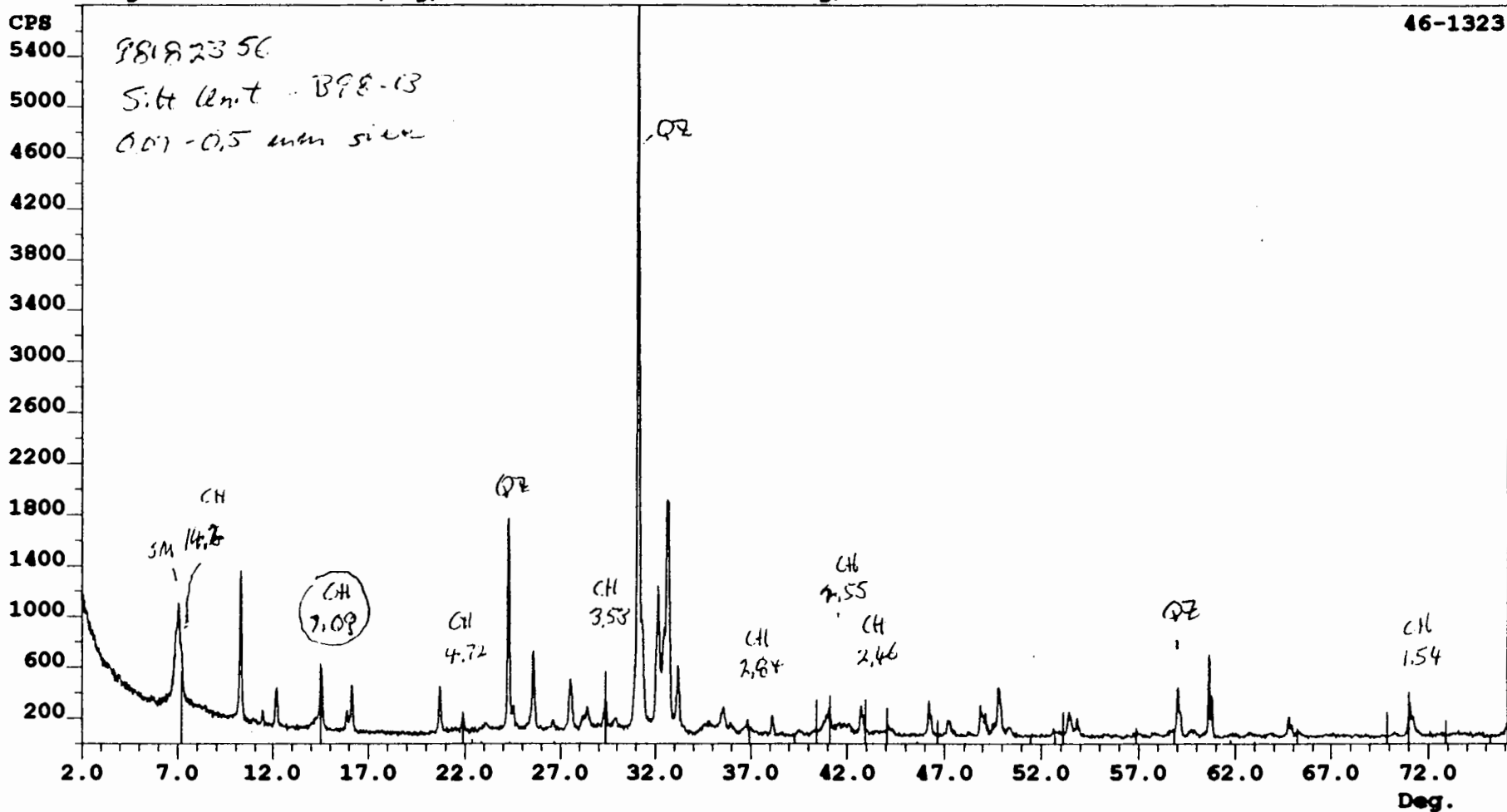


D-9

File: fc56, ID: 2.0/4.0//0.5/0.3

Date: 12/09/98 16:16 Step : 0.020° Cnt Time: 1.200 Sec.

Range: 2.00 - 76.00 (Deg) Cont. Scan Rate : 1.00 Deg/min.



D-10

Attachment 3. Notes on Microscopic Observations

Samples are from boreholes B98-12 and B98-13, collected by Mark Pugh and Sonia Fernandez, R.F. Weston, for the Frontier Hard Chrome site, Vancouver, Washington, April 27, 1998. Microscopic observations were made in October 1998 at the EPA Manchester Laboratory using a Wild M5A stereomicroscope with incident light.

Field Sample SBR1-9813-0160

Lab Number 98182379, cut pebbles.

4 pebbles:

- 2 w/ black coating, one very thick; one of these also with patchy brown coating.
- 1 w/ patchy white coating and patchy brown coating; 1 mm tan alteration rind.
- 1 w/ no coating.

Lab Number 98182350 >2 mm, gravel

- 50% black angular pebbles coated with tarry material (asphalt-coated basalt).
- remainder brown/gray pebbles.
- <5% white-coated rocks (concrete).
- <1% wood.

Lab Number 98182351, 0.5-2 mm, coarse sand

- gray sand.
- grain coatings: 50% black granular, 5% white.
- grain color: 40% gray, 10% brown, 5% beige (quartz), <1% white, <1% red/orange, <1% brick red.
- <1% wood splinters.

Lab Number 98182352 0.07-0.5 mm, fine sand

- very dark gray sand (10YR 3/1).
- grain color: 80% black/brown/gray granular clumps, 20% beige (quartz), 1% mica, 1% tan/orange.

Field Sample SBR1-9813-0210

Lab Number 98182380, cut pebbles.

1 pebble:

- 1 w/ patchy tan coating; 1 mm tan alteration rind.

Lab Number 98182354 >2 mm, gravel

- 20% black, angular pebbles.
- 20% white-coated pebbles.
- 20% orange-stained brown pebbles.
- <1% coarse quartz.

Lab Number 98182355, 0.5-2 mm, coarse sand

- gray sand.
- grain coatings: 20% black granular, 30% orange/tan, 1% white.
- grain color: 10% gray, 5% brown, 20% tan, <1% beige/tan, < 1% white, <1% clear, 30%orange, 0% brick red.
- <1% wood splinters.

Lab Number 98182356 0.07-0.5 mm, fine sand

- grayish brown sand (10YR 5/2).
- grain color: 50% beige (quartz), 5% mica, 40% tan/brown/orange, 1% black.

Field Sample SBR1-9813-0210 duplicate

Lab Number 98182381, cut pebbles

1 pebble:

- 1 w/ patchy tan coating.

Lab Number 98182358 >2 mm, gravel

- 30% black, angular pebbles (basalt).
- <5% white-coated pebbles.

Lab Number 98182359, 0.5-2 mm, coarse sand

- gray sand.
- grain coatings: 30% black granular, 0% orange/tan, 5% white.
- grain color: 10% gray, 1% brown, 10% tan, 0% beige, 1% white, <1% clear, 5%orange, <1% brick red.
- <1% wood splinters.

Lab Number 98182360 0.07-0.5 mm, fine sand

- gray sand (10YR 5/1).
- grain color: 60% beige (quartz), 5% mica, 30% orange/tan/brown, 2% black.

Field Sample SBR1-9813-0250

Lab Number 98182382, cut pebbles

6 pebbles:

- 5 w/ patchy tan coatings.
- 1 w/ no coating; 2 mm alteration rind.

Lab Number 98182362 >2 mm, gravel

- 10% dark, gray angular pebbles.
- 30% rounded orange-stained pebbles.
- <1% coarse-grained quartz.

Lab Number 98182364 0.07-0.5 mm, fine sand

- grayish brown sand (10YR 5/2).
- grain color: 40% beige (quartz), 5% mica, 50% orange/tan/brown, 5% gray, 1% black.

Field Sample SBR1-9812-0160

Lab Number 98182383, cut pebbles

7 pebbles:

- 2 w/ white coatings.
- 3 w/ tan coatings.
- 1 w/ white and tan coating.
- 1 w/ no coating.

Lab Number 98182366 >2 mm, gravel

- 30% black angular fragments similar to 50 (basalt).
- 20% round to angular white-coated gray pebbles (concrete).
- 10% orange-stained pebbles.
- < 5% coarse quartz
- <5% coarse granite.

Lab Number 98182367, 0.5-2 mm, coarse sand

- gray sand.
- grain coatings: 20% black granular, 0% orange/tan, 10% white.
- grain color: 20% gray, 10% brown, <1% tan, 5% beige, 10% white, <1% clear, 5% orange, <1% brick red.
- 0% wood splinters.

Lab Number 98182368 0.07-0.5 mm, fine sand

- dark gray sand (10YR 4/1).
- grain color: 30% beige (quartz) 1% mica, 30% orange/tan/brown, 30% black.

Field Sample SBR1-9812-0220

Lab Number 98182384, cut pebbles

2 pebbles:

- 2 w/ black coatings.

Lab Number 98182370 >2 mm, gravel

- 20% black, angular pebbles (basalt).
- <1% coarse quartz.
- < 5% orange-stained pebbles.
- 10% wood.

Lab Number 98182371, 0.5-2 mm, coarse sand

- gray sand.
- grain coatings: 30% black granular, 0% orange/tan, 1% white.

- grain color: 20% gray, 0% brown, 10% tan, 1% beige, 5% white, 0% clear, 20%orange, 1% brick red.
- 5% wood splinters.

Lab Number 98182372 0.07-0.5 mm, fine sand

- gray sand (10YR 5/1).
- grain color: 70% beige (quartz), 1% mica, 20% orange/brown/tan, 5% black.

Field Sample SBR1-9812-0260

Lab Number 98182385, cut pebbles

8 pebbles:

- 2 w/ very patchy brown coatings.
- 6 w/ no coating.

Lab Number 98182374 >2 mm, gravel

- 20% dark gray, angular pebbles.
- 1% coarse quartz.
- 20% brown to orange-stained rounded pebbles.
- <1% wood.

Lab Number 98182375, 0.5-2 mm, coarse sand

- gray sand.
- grain coatings: 5% black granular, 0% orange/tan, <1% white.
- grain color: 30% gray, 5% brown, 5% tan, 1% beige, 5% white, <1% clear, 10%orange, 1% brick red.
- <1% wood splinters.
- <1% brown mica.

Lab Number 98182376 0.07-0.5 mm, fine sand

- gray sand (10YR 5/1).
- grain color: 60% beige (quartz), 5% mica, 30% orange/brown/tan, 5% gray.

APPENDIX B

Laboratory Report for Scanning Electron Microscope/Electron Probe Microanalysis.

Cannon Microprobe



**ELECTRON MICROPROBE and
SCANNING ELECTRON MICROSCOPE
ANALYSIS of CHROMIUM BEARING
SEDIMENTS from FRONTIER HARD CHROME**

PO# 92005L
Invoice # 99 - 240
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Description of Samples

18 samples of different size fractions from among the EPA sample series 98182350-77

Purpose of Analysis

Determine mode of occurrence of chromium, barium and manganese in the samples.

Sample Preparation

Four types of sample mounts were prepared and analyzed, though all types were not prepared for each sample.

The first type is that of a polished thick section in which the as received soil particles were emulsed in Buehler two part "Sampl-Kwick plastic and the cured casting then ground and polished to expose the particles and fragments in cross section. The castings consist of single 0.5 inch diameter round mounts of random particles from the minus 0.07 mm in some samples and the 0.07mm to 0.5 mm in others. In two samples coarser fractions were analyzed.

The second type was prepared as a loose dusting of the finest particles directly upon conductive carbon tape.

The third type consisted of a dusting as above, but as fine concentrates from a Frantz Magnetic Barrier Separator.

The fourth type was prepared as a gravity concentrate using careful hand panning of the fine fractions. The concentrate was then cast in Sampl-Kwick, and then ground and polished.

Electron Microprobe Analysis and Instrumentation

The analysis was conducted in an ARL SEMQ electron microprobe at 20KV and 50 nA beam current. The instrument is equipped with six wavelength dispersive x-ray spectrometers (WDS) and a Kevex energy dispersive x-ray spectrometer (EDS). Semi-quantitative analyses were conducted using the WDS system. Rapid identifications of phases and full spectra were obtained

with the EDS system. The sample was imaged with a television rate backscattered electron detector. Beam co-axial light optics are used for cathodoluminescence and color observations.

The WDS analysis was carried out using mineral standards and manual observation of the x-ray count rates of their readout bay. Background count rates were established for both low atomic number silicates and higher atomic number metals and oxides. The elemental analyses were determined using 10 second counting intervals. Count totals on unknowns minus appropriate background counts were compared to count rates for the standards to provide the elemental concentrations used in the report. Aside from the atomic number background factor, other matrix or fluorescence corrections were not employed.

The standards used were as follows: Cr = chromite, Ba = benitoite, Mn = syn MnS, Fe = hematite. The background standards used were Cr, and Ba free hematite. This hematite contained 0.04 weight % Mn and that figure represents the absolute minimum detection limit for that element. Cr and Ba have detection limits of 0.02 to 0.04% weight per cent via WDS.

The detection limit for Cr via EDS is about 0.2%.

Images were acquired using Digisem hardware and software created by ELMDAS of Alexandria, PA. The images are of the *back scattered electron* (BSE) type in which contrast is a function of the atomic number of the subject. Phases with a high atomic number are brighter than those with lower atomic numbers.

Analyst

The analyst on all instruments and the author of the report was Bart Cannon

Analyses of Standards

Phase	Al ₂ O ₃	BaO	FeO	MgO	Mn	MnO	SiO ₂	Cr ₂ O ₃	S
Hematite	--	--	99.1	--	--	0.04	--	--	--
Benitoite	--	33.9	--	--	--	--	43.6	--	--
Chromite	9.5	--	30.9	5.9	--	0.8	--	49.3	--
MnS	--	--	--	--	63.2	--	--	--	36.8

Explanation of Terms, Abbreviations, Annotation Scheme.

EDS refers to energy dispersive x-ray spectroscopy. and EDS spectrum shows the x-ray spectrum from Na through U. The spectrum number appears in the lower center of each spectrum. The code (S - 1) etc. is followed.

WDS refers to wavelength dispersive x-ray spectroscopic analysis. WDS uses scanning spectrometers that are tuned to a specific x-ray wavelength. Sensitivity is more than an order of magnitude better than EDS.

Photos are scanning electron micrographs using back scattered electron imaging. Photo number refers to sample number followed by photo series number. The series number is referenced within each sample' photo log in the text section of the report. The code (P-1) etc is used.

X-Ray Maps are images obtained in scanning electron microscope mode with two of the wavelength dispersive x-ray spectrometers tuned to manganese and chromium. X-ray counts are integrated with the image scan and plotted as dots where detected. In the case of chromium 0.4% Cr₂O₃ and higher are plotted as dark blue and 0.3% Cr₂O₃ and lower are plotted as light

blue. All values of manganese are plotted as medium red. The quantitative information is in reality fairly crude at trace concentrations since the dwell time at each pixel is on 0.1 second, not long enough for decent counting statistics for trace concentrations. The maps are indexed as X-1 through (X-3).

tr = trace concentration of 0.25% or less.

nd = sought, but not detected.

na = not analyzed for.

RESULTS

981823 - 50 -- > 2mm Sand and Gravel -----

Chromium was detected as a trace constituent in rare titanomagnetite. Black coatings easily observed by 10 X stereo microscope examination of coarse pebbles were determined to be asphalt as indicated by lack of EDS x-ray peaks and the coating's solubility in MEK.

WDS		Cr2O3	MnO	BaO	FeO
50 sg 01	titanomagnetite	0.04	tr?	nd	~94
50 sg 02	titanomagnetite	0.06	tr?	nd	~94

981823 - 51 0.5 - 2.0 mm -----

Chromium was detected as a trace constituent in rare titanomagnetite and magnetite. These minerals occur in the ground mass of basalt grains. Analyses below are representative of more than 25 grains analyzed. Possible trace chromium may exist in fayalite or enstatite. Barium was not detected. Manganese occurs as a trace to minor constituent in magnetite, titanomagnetite and ilmenite.

WDS		Cr2O3	MnO	BaO	FeO
51 01	titanomagnetite	0.20	0.06	nd	~88
51 02	titanomagnetite	0.14	0.5	nd	~91
51 03	magnetite	0.3	nd	nd	~97
51 04	magnetite	0.02	nd	nd	~95
51 05	titanomagnetite	0.04	0.7	nd	~90

981823 - 52 - < 0.07 - 0.5 mm bulk -----

Chromium is associated with rare grains of titanomagnetite. Barium was not detected. Manganese was encountered in titanomagnetite and ilmenite.

WDS		Cr2O3	MnO	BaO	FeO
52 blk 01	titanomagnetite	0.03	0.05	nd	~93
52 blk 01	ilmenite	tr?	1.24	nd	~44
52 blk 02	titanomagnetite	0.08	0.14	nd	~91
52 blk 03	titanomagnetite	~0.2	tr?	nd	~94

Photos

52 blk 01 (P-8) Ilmenite at b. Pyroxene at a and plagioclase at c.
Bright grains at upper and outer margin of the
ilmenite are titanomagnetite.

X-Ray Map

52 blk 03(X-1). Puzzling grain of titanomagnetite with unusual ragged rim. Chromium concentration increases toward the core of the grain.

981823 - 52 - Gravity Concentrate -----

Four grains of chromite were found. Nine grains of titanomagnetite were encountered, most containing less than 0.2% Cr₂O₃, but one grain contained 3.2% Cr₂O₃. (See 52-04 below). Barium was not detected. Manganese occurs in titanomagnetite as a minor constituent and intergrown as an iron, manganese hydroxide in one large grain of Fe hydroxide.

EDS

52 gr con 02a(S-6) Mn,Ca Fe hydroxide
 52 gr con 02b(S-7) Fe hydroxide. Trace Cr via WDS only.
 52 gr con 02c(S-8) Fe hydroxide. Trace Cr via WDS only.
 52 gr con 04 (S-1) Cr, Mn bearing titanomagnetite

WDS

	Cr ₂ O ₃	MnO	BaO	FeO
52-02a Fe,Mn hydroxide	0.06	9.7	nd	~41
52-02b Fe hydroxide	0.04	0.1	nd	~53
52-02c Fe hydroxide	0.06	0.2	nd	~55
52-04 titanomagnetite	3.2	0.6	nd	~47

Photos

52 gr con 01 = Fe hydroxides. Fe hydroxide at "a" of greater hardness than at "b" and it shows dessication cracks.
 52 con 02 = Enlarged easterly view of image of 52 gr con 01.
 a=(S-6) Fe,Ca,Mn hydroxide. b=(S-7) Fe hydroxide.
 c=(S-8) Fe hydroxide.

981823 - 56 - 0.07 - 0.5 mm bulk -----

Iron bearing aluminum silicates form fine grained aggregates with up to a 2.5 % MnO and showing up to 0.3% Cr₂O₃ and averaging about half of that. The silicate is a mixture of minerals which have probably agglomerated during sample processing, but may contain important chlorite. Barium was not detected. Manganese occurs as a trace to minor constituent in magnetite and titanomagnetite and as a minor constituent in agglomerates of Fe,Al silicate clays and chlorites.

EDS

56 06 = (S-2) Fe, Al silicates with coarser quartz and plagioclase.
 56 07 = (S-3) Fe, Al silicates with coarser quartz and plagioclase.

WDS

	Cr ₂ O ₃	MnO	BaO	FeO
56 blk 01 Al,Fe silicate	0.02	0.3	nd	~ 9
56 02a Al,Fe silicate	0.02	0.3	nd	~11
56 002a Al,Fe silicate	0.03	0.4	nd	~13
56 03a Al,Fe silicate	0.02	0.3	nd	~ 9
56 003a Al,Fe silicate	0.04	0.4	nd	~ 7
56 004a Al,Fe silicate	0.3	0.6	nd	~ 7
56 005a Al,Fe silicate	0.02	1.2	nd	~ 9
56 06 Al,Fe silicate(S-2)	0.02	2.7	nd	~ 7
56 07a Al,Fe silicate(S-3)	0.14	8.1	nd	~ 8

Photos

56 blk 01 Al,Fe silicate with trace Cr at "a". (P-1)
 56 02 Al,Fe silicates and coarse quartz and plagioclase at "a". (P-1)
 56 002 Fine Al,Fe silicates at "b" with coarser quartz grains. (P-1)
 56 03 Al, Fe silicates at "a" with coarser hard silicates. (P-1)
 56 003 Al, Fe silicates at "a" with plagioclase at "b". (P-2)
 56 004 Al, Fe silicates at "a" with quartz at "b". (P-2)
 56 005 Al Fe silicates at "a". (P-2)
 56 06 Al,Fe silicates at "a" and coarse quartz and plagioclase. (P-2)
 56 07 Al,Fe silicates at "a" and coarse quartz and plagioclase. (P-2)

X-Ray Map

56 bulk (X-2). Fe, Al silicate agglomerate showing trace chromium distributed according to unknown mineralogical variation. Trace manganese shows only slight distribution trend at the upper center of the Fe Al silicate grain.

981823 - 56- coarse Gravity Concentrate -----

Chromium rich phases are not common. One unusual grain of chromian, titanian Magnetite has 17% Cr₂O₃. Much of the magnetite in the sample contains trace to 0.04% Cr₂O₃. Barium was not detected. Manganese occurs as a minor constituent in titanomagnetite and a trace to minor constituent in magnetite.

EDS

56 gr con 01a = (S-4) Magnetite grain. Cr detected by WDS, not by EDS.
56 gr con 011 = (S-5) Chromian titanomagnetite.

WDS

		Cr ₂ O ₃	MnO	BaO	FeO
56-01	Magnetite (S-4)	0.02	0.4	nd	~91
56-011	CrTi magnetite (S-5)	~17.0	0.8	nd	~24

981823 - 56 - MF-1 Magnetic Concentrate, Fine Fraction -----

Fifteen grains of 40 to 80 um grains of chromium bearing metallic iron (0.4% to 3.2% Cr₂O₃) were found. These grains have been partially converted to iron hydroxides with no chromium present in the encrusting hydroxide. Also 30 grains of chromium free metallic iron. Grains of nearly pure, chromium free iron are present and more abundant than the chromium bearing iron. A few grains of high chromian titanomagnetite showing MnO of 3% and Cr₂O₃ at 1.2%.

No barium was noted, but manganese occurs, as mentioned just previously and in most of the titanomagnetites in concentrations between trace and 0.2 weight per cent MnO.

EDS

MF1 01a(S-9) Magnetite with minor Cr and Mn.
MF1 052(S-10) Titanian magnetite with minor Cr and Mn.
MF1 06A(S-11) Titanomagnetite. Cr only detected via WDS.
MF1 06B(S-12) Titanomagnetite. Cr detected.
MF1 06C(S-13) Titanian magnetite with minor Cr.
MF1 07a(S-14) Titanian, chromian magnetite.
MF1 08a(S-15) Unknown Fe Cr phase inter grown with Fe,Al silicates.
MF1 08b(S-16) Fe,Al secondary(?) silicate on pyroxenes and plagioclase.
MF1 08c(S-17) Plagioclase. Not denoted in images as "c".
MF1 09a(S-18) Chromium bearing iron metal.
MF1 09b(S-19) Fe,Ca,Al silicate encrustation on iron metal.
MF1 10 (S-20) Iron metal with minor Cr and Mn.

WDS

		Cr ₂ O ₃	MnO	BaO	FeO
56-MF 101(S-9)	magnetite	0.45	0.4	nd	~96
56-MF 104	magnetite	0.05	0.08	nd	~96
56-MF 102a	iron metal	0.15	0.2	nd	~98
56-MF 102b	iron hydroxide	nd	0.1	nd	~77
56-MF 102c	iron hydroxide	nd	0.1	nd	~79
56-MF 105(S-10)	magnetite	0.55	0.3	nd	~96
56-MF 106a	titanomagnetite	0.08	0.1	nd	~74
56-MF 106b	titanomagnetite	0.35	0.1	nd	~74
56-MF 106c	Ti magnetite	0.40	0.1	nd	~74
56-MF 107	Ti magnetite	3.80	0.2	nd	~86
56-MF 108a	CrMn iron phase	6.90	1.6	nd	~89

56-MF 108b pyroxene 1.30 0.8 nd ~10

Photos

56 MF1 01(P-2) Magnetite
 56 MF1 02(P-3) Cr bearing iron metal with alteration to Fe hydroxides.
 56 MF1 04(P-3) Cr bearing iron metal with alteration to Fe hydroxides.
 56 MF1 05(P-3) same as MF1 05.
 56 MF1 06(P-3) Titanomagnetite and magnetite.
 56 MF1 07(P-3) Chromian titanian magnetite at "a" with pyroxene at "b".
 56 MF1 08(P-4) Cr rich iron and Fe,Al silicates encrusting plagioclase and pyroxene bearing basalt fragment. Synthetic origin?
 56 MF1 08(P-4) High magnification of Cr rich iron crust.
 56 MF1 09(P-3) Cr bearing iron metal with Cr free Fe,Al silicate crust.
 56 MF1 10(P-4) Iron metal with minor Cr and Mn and Cr and Mn crust.

981823 56 MF-2 Magnetic Concentrate, Fine Fraction -----

Grains of titanomagnetite are common Chromium concentrations range from 0.0 to 0.3% Cr₂O₃. Most titanomagnetite does not contain detectable chromium. Two grains of chromite were noted.

EDS

56 MF2 04(S-21) Chromian titanomagnetite.

WDS	Cr ₂ O ₃	MnO	BaO	FeO
56 MF2 01 magnetite	tr	0.1	nd	~97
56 MF2 02 titanomagnetite	0.2	0.1	nd	~89
56 MF2 03 titanomanetite	0.2	0.3	nd	~88
56 MF2 04 titanomagnetite	1.4	0.2	nd	~89

Photos

56 MF2 04(P-4)(S-21) Chromian titanomagnetite.

981823 56 MP-2 Magnetic Concentrate -----

This sample contains a few grains of an iron manganese aluminum silicate with minor potassium and calcium and from 0.2% to 0.4% Cr₂O₃. A single grain of an amphibole with trace chromium was noted. An ilmenite grain was found which contained 0.03% Cr₂O₃. It was intergrown with a magnesium silicate which may be enstatite and which contains trace chromium. Titanian and titanomagnetite are common, but less than 10% of the grains show more than 0.2% Cr₂O₃. Most show 0.03% or less. Also noted were a few grains of titanium - free, but chromium bearing (up to 15.4% Cr₂O₃) spinel were found (S-24).

EDS

56 MP2 02 (S-22) titanomagnetite with trace Cr in FeAl silicate.
 56 MP2 03 (S-23) Cr magnetite inter grown with Cr spinel
 56 MP2 03c (S-24) Cr Spinel.
 56 MP2 04 (S-25) Amphibole with trace Cr.

WDS	Cr ₂ O ₃	MnO	BaO	FeO
56 MP2 - 1 ilmenite	0.03	1.4	nd	~50
56 MP2 - 2 enstatite fayalite	0.02	0.3	nd	~ 7

Photos

56 MP2 01 (P-4) FeAlMn silicate with trace Cr at "a" and ilmenite as bright grain with 0.03% Cr₂O₃.
 56 MP2 02 (P-4) Cr bearing FeAl silicate at "a". Plagioclase at "b" and Cr bearing titanomagnetite as bright grain.
 56 MP2 03c(P-5) Cr bearing spinel zones in Cr bearing magnetite.
 56 MP2 04 (P-5) Magnetite at "a" plagioclase at "c" and Cr bearing amphibole at "b".

981823 - 56 MP-4 Magnetic Concentrate -----

Chromium bearing phases are very uncommon. A few grains of a chromium bearing pyroxene were found. Five to ten grains of metallic tin were encountered. Lead was associated with one of the grains and may represent a particle of solder. No barium phases were encountered. Ilmenite, which is rare contains up to about 0.02% Cr₂O₃ and up to 3.3% MnO.

WDS		Cr ₂ O ₃	MnO	BaO	FeO
56 MP4 01	pyrx or amph	0.02	0.30	nd	~4.0
56 MP4 02	ilmenite	0.02	3.30	nd	~41.0

Photos

56 MP4 01(P-5) Pyroxene or amphibole with trace Cr. EDS spectra similar to S-25.

981823 - 57 - Bulk - < 0.07mm polished -----

Numerous Fe,Al silicate agglomerates containing nil to 0.02% Cr₂O₃.

EDS

57 07(S-26) Fe,Al silicate with minor Mn and trace Cr.
57 08(S-27) Fe,Al silicate with minor Cr.

WDS		Cr ₂ O ₃	MnO	BaO	FeO
57 01	Fe,Al silicate	0.03	0.5	nd	~4.0
57 04	Fe,Al silicate	0.02	0.1	nd	~4.0
57 06a	Fe,Al silicate	0.02	0.4	nd	~5.2
57 07 (S-26)	Fe,Al silicate	0.03	0.9	nd	~10.0
57 08 (S-27)	Fe,Al silicate	0.15	0.1	nd	~3.9

Photos

57 06(P-5) FeAl silicate with 0.02% Cr₂O₃.
57 08(P-5) (S-27) Fe Al silicate with 0.04% Cr₂O₃ and. MnO

981823 - 57 - < 0.07mm Gravity Concentrate -----

At least sixteen grains of 20-30 micron chromite in the half of the sample which was concentrated. A few grains of chromium bearing titanomagnetite were encountered.

WDS		Cr ₂ O ₃	MnO	BaO	FeO
57 gr con 01	chromite	~57.0	4.2	nd	8.3
57 gr con 02	titanian magnetite	0.1	0.4	nd	~94.0

Photos

57 gr con 01(P-5) Loose grain mount. Chromite euhedron at "a".

981823 - 64 - bulk -----

This sample contains rare Fe,Al silicate agglomerates which contain trace chromium and few pyroxenes with trace chromium and major manganese(S-31). Also noted was a chromium-titanium bearing pyroxene (S-31). An unknown chromium-titanium phase contained 32.0% Cr₂O₃.

EDS

64 blk 01(S-28) Fe,Al silicate with trace Cr.
64 06 blk 01(S-30) Unknown CrTi phase.

64 06 blk 02(S-31)Mn Fe Al pyroxene.

WDS			Cr2O3	MnO	BaO	FeO
64 blk	01(S-28)		0.1	tr	nd	~5.5
64 blk 06	01(S-30)	Unk CrTi	~32.0	0.04	nd	~57.0
64 blk 06	02(S-31)	pyroxene	0.2	~21.00	nd	~31.0

Photos

64 blk 01 (P-6) Unknown CrTi phase.
64 blk (P-6) Cr bearing Fe,Al silicate.

981823 - 64 coarse gravity con -----

Ten grains of titanian magnetite with from 0.3 to 2.3% Cr2O3 were found. Several grains of chromium bearing iron containing from 6.1 to 16.0% Cr2O3 were found. The high chromium steel grains do not show alteration to Fe hydroxides. Some very manganese rich ilmenites occur.

EDS

64 gr con 01(S-32) Cr bearing titanian magnetite.
64 gr con 02(S-33) Cr,Mn bearing titanian magnetite.
64 gr con 03(S-34) Chrome steel.
64 gr con 04(S-35) Chrome steel.

WDS			Cr2O3	MnO	BaO	FeO
64 gr con 01(S-32)	magnetite		1.9	0.6	nd	~84.0
64 gr con 02(S-33)	magnetite		2.3	0.3	nd	~84.0
64 gr con 03(S-34)	Cr iron		6.1	1.0	nd	~92.0
64 gr con 04(S-35)	Cr iron		9.6	0.7	nd	~92.0
64 gr con 05	Cr iron		~16.0	0.3	nd	~81.0
64 gr con 06	ilmenite		0.1	9.3	nd	~39.0
64 gr con 07	ilmenite		tr	7.2	nd	~40.0

981823 - 65 - 0.07mm Gravity Concentrate -----

Four grains of 20-30 micron chromite grains were found. A single 60 micron grain of somewhat etched stainless steel containing major chromium was found and photographed (65 01 P-6). Two grains of titanian magnetite with trace chromium were found.

EDS

65 gr con 01A(S-36) Etched looking stainless steel.

WDS			Cr2O3	MnO	BaO	FeO
65 gr con 01A(S-36)	Stainless		~21.0	0.3	nd	~77.0
65 gr con 02	chromite		~54.0	0.9	nd	~17.0
65 gr con 03	magnetite		0.03	0.1	nd	~94.0
65 gr con 04	magnetite		0.02	0.3	nd	~93.0

Photos

65 01 (P-6) Corroded stainless steel grain.

981823 - 72 - bulk -----

Iron aluminum silicate agglomerates containing trace chromium are fairly common. Several pyrite grains were observed. One grain of siderite with inter grown iron hydroxides was noted. All of the latter phases contained trace chromium. One grain of a complex hard silicate contained major chromium (S-37).

EDS

72 blk 02 (S-40) Fe,Al silicate with inter grown apatite.

72 03 (S-37) Complex silicate with major chromium..
 72 blk 03a(S-41) siderite with trace Cr.
 72 blk 03b(S-42) Fe,Al silicate with minor chromium.
 72 blk 03c(S-43) Fe,Al silicate with minor chromium.
 72 blk 04a(S-44) Fe,Mg,Al silicate with trace chromium.
 72 blk 05 (S-45) Fe,Mn,Al silicate with trace chromium.

WDS		Cr2O3	MnO	BaO	FeO
72 blk 01 (P-6)	Fe,Al silicate	0.06	tr	nd	~9.0
72 blk 02 (S-40)	Fe,Al Ca silicate	1.8	1.6	nd	~27.0
72 03 (S-37)	complex silicate	~16.0	1.1	nd	~24.0
72 blk 03a(S-41) (P-6)	siderite	0.2	0.2	nd	~39.0
72 blk 03b(S-42) (P-6)	Fe,Al silicate	0.7	0.4	nd	~36.0
72 blk 03c(S-43) (P-6)	Fe,Al silicate	0.9	0.3	nd	~15.0
72 blk 04 (S-44) (P-6)	Fe,Al silicate	0.4	0.1	nd	~10.0
72 blk 05 (S-45) (P-7)	Fe,Mn silicate	0.3	~19.0	nd	~22.0

Photos

72 blk 02(P-6) (S-40) Fe,Al silicates with trace Cr and apatite.
 72 blk 03(P-6) (S-41-43) Siderite "a" and Fe,Al silicates at "b,c".
 72 blk 04(P-6) Fe,Mg silicate with trace Cr at "a" and enstatite at "b"
 72 blk 05(P-7) Fe,Al silicate with trace Cr.

X-Ray Map

72 blk 02 (X-3). Trace chromium shows a correlation with the "soft" minerals in this Fe,Al silicate agglomerate. Manganese does not show a distribution trend.

981823 - 72 - Gravity Concentrate -----

A few titanian magnetites with trace chromium were encountered. Most of the chromium appears to exist as chromium steel particles. It is of interest that the Fe,Al silicate oxidation crusts on such grains do not show chromium in their spectra. Some ilmenites contain up to 4.0% MnO.

EDS

72 gr con 01(S-46) Cr bearing iron.
 72 gr con 02(S-47) Cr bearing iron. Cr free Fe,Al silicate at "b".

WDS		Cr2O3	MnO	BaO	FeO
72 gr con 01(S-46)	Cr iron	4.8	0.3	nd	~92.0
72 gr con 02(S-47)	Cr iron	4.6	0.4	nd	~86.0
72 gr con 03	titanomagnetite	0.04	0.1	nd	~89.0
72 gr con 04	ilmenite	tr	4.0	nd	~44.0

Photos

72 gr con 01(S-46) (P-7) Cr iron
 72 gr con 02(S-47) (P-7) Cr iron

981823 - 76 - 0.07 - 0.5 mm Bulk -----

Chromium was noted in uncommon grains of the iron aluminum silicate agglomerates.

EDS

76 blk 05(S-48) Fe,Al,Mg,Ca silicate with trace Cr and minor Mn.

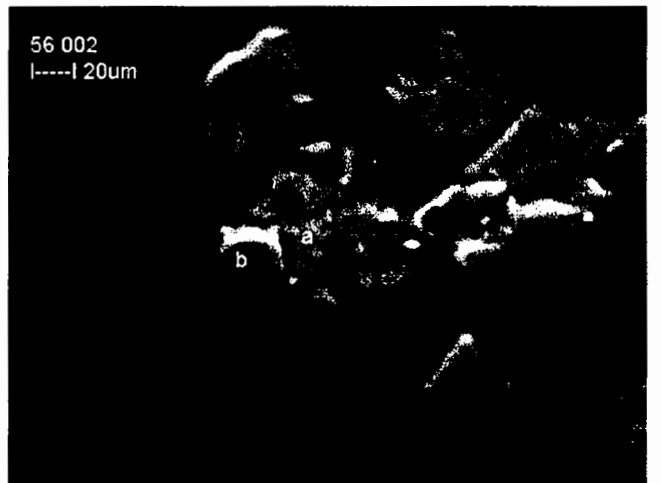
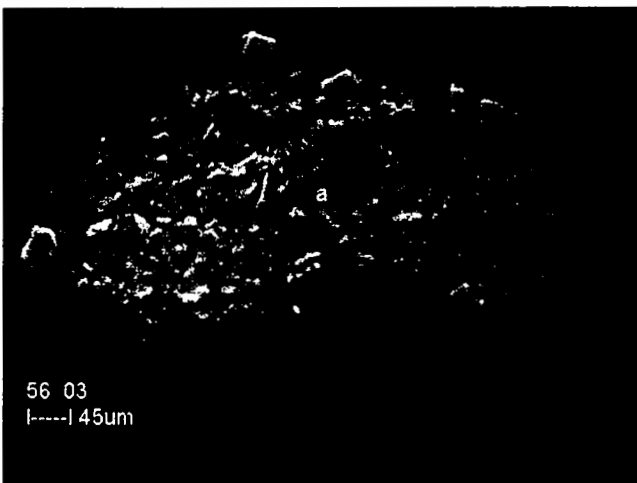
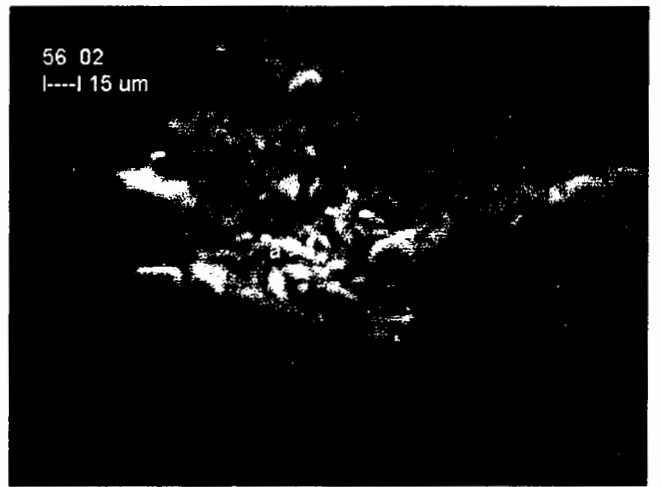
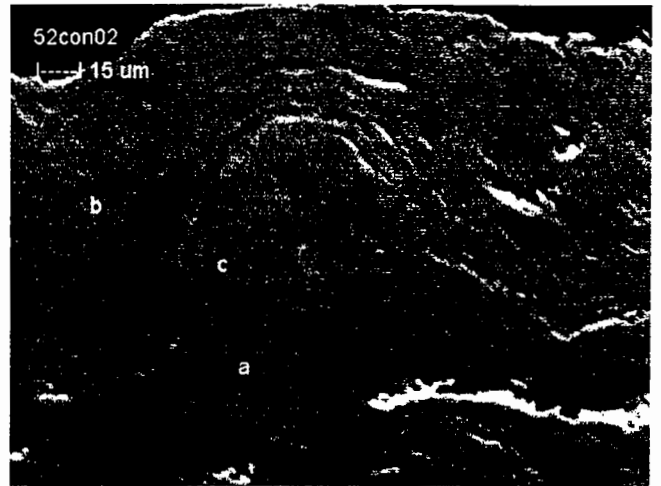
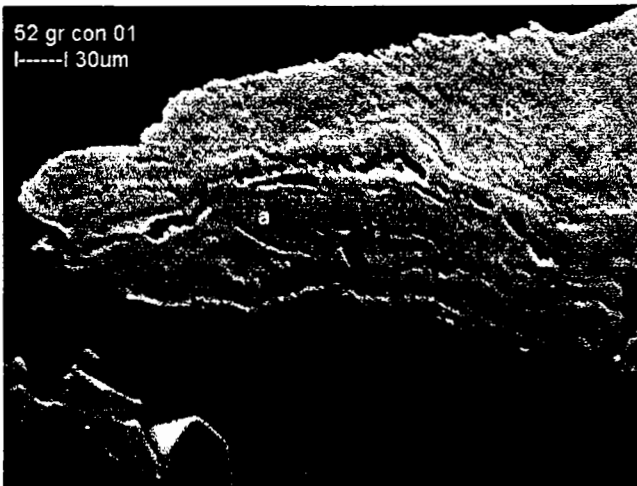
WDS		Cr2O3	MnO	BaO	FeO
76 blk 01(S-48)	Fe,Al silicate	0.5	1.1	nd	~19.0
76 blk 02	Fe,Al silicate	0.04	0.2	nd	~12.0

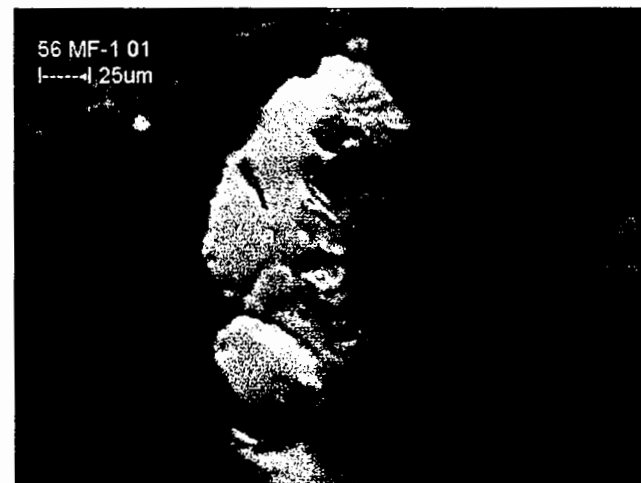
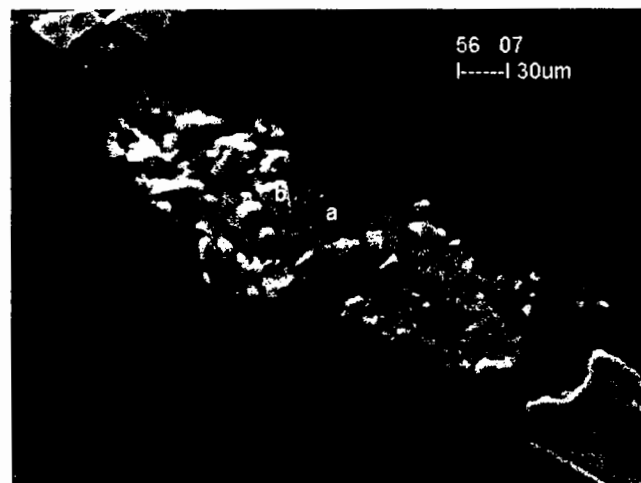
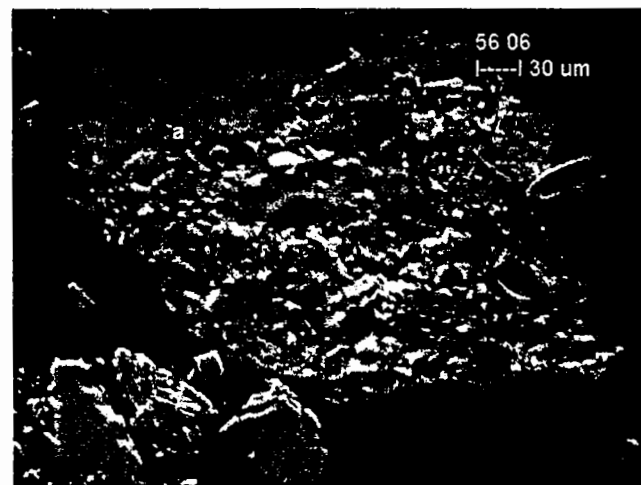
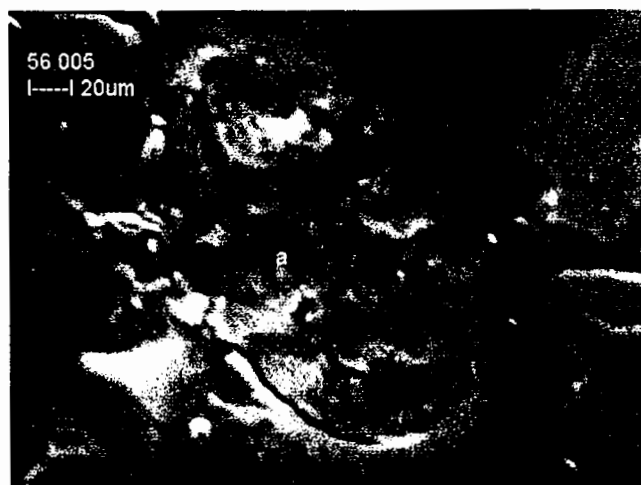
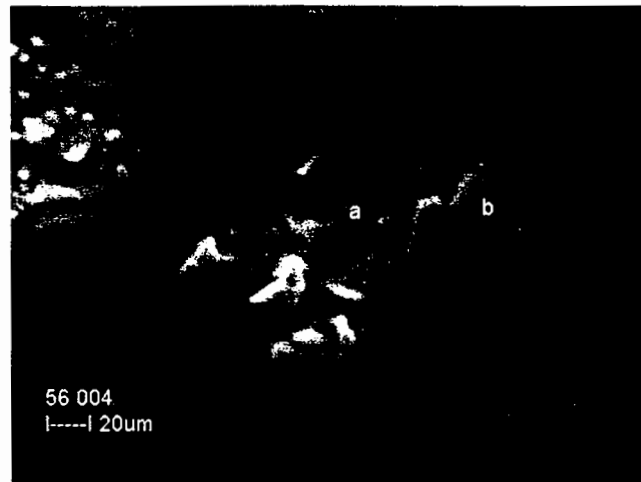
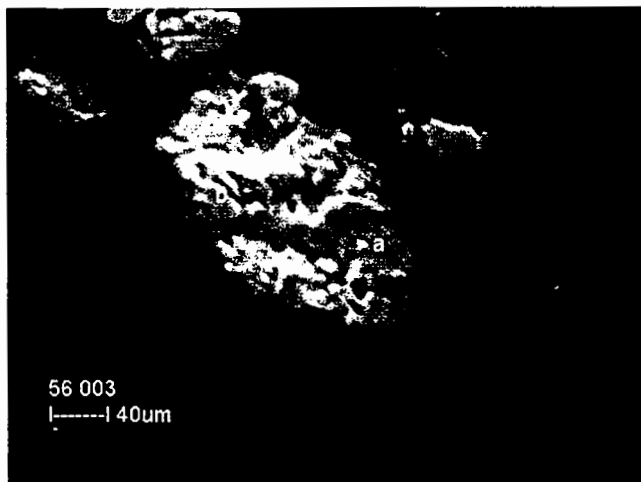
Photos

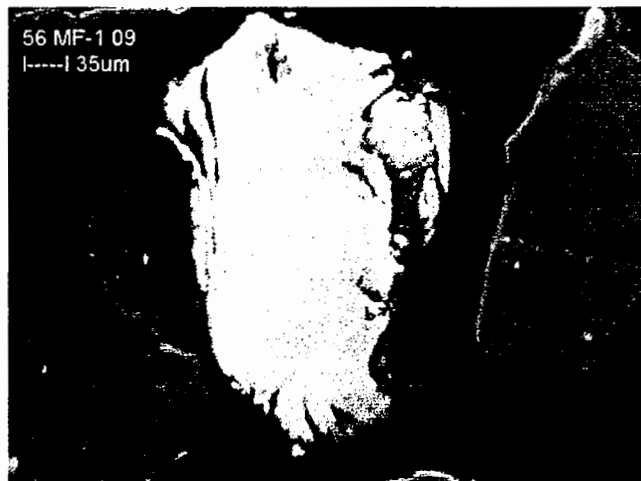
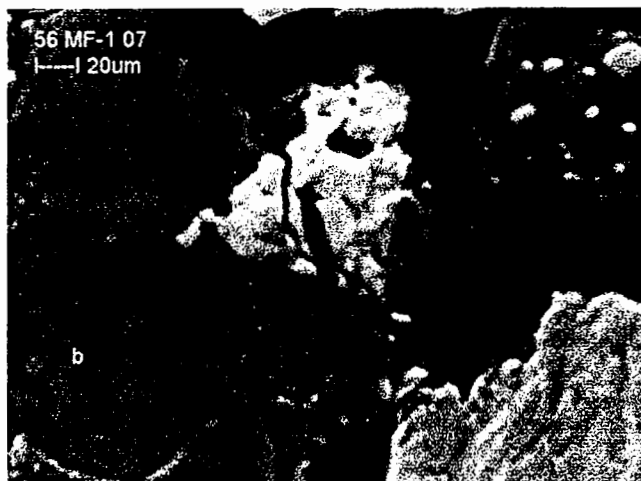
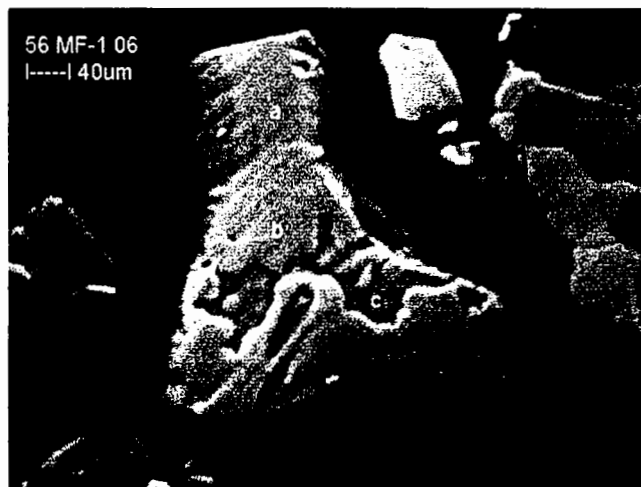
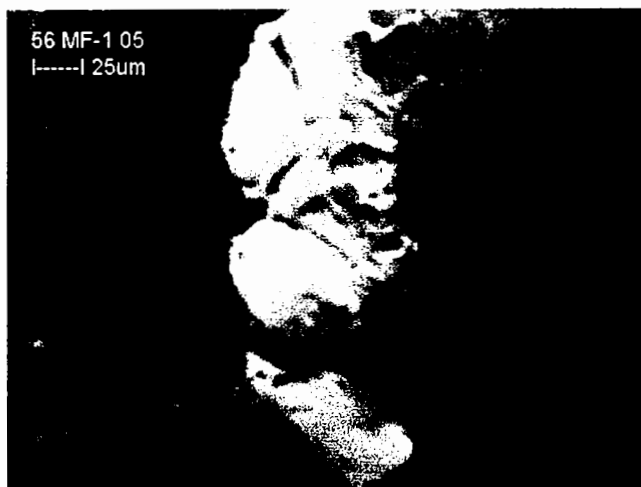
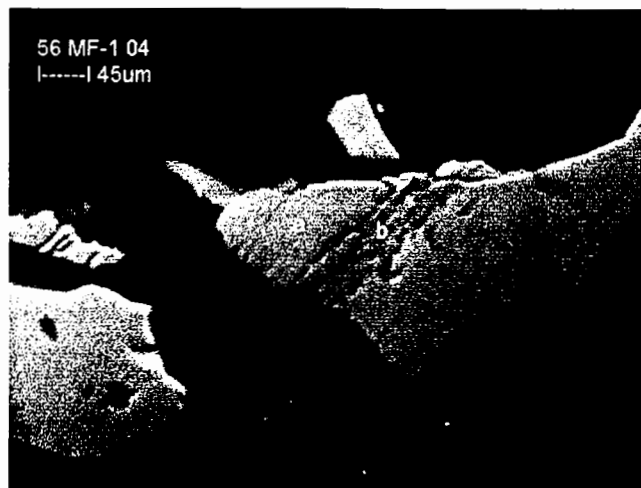
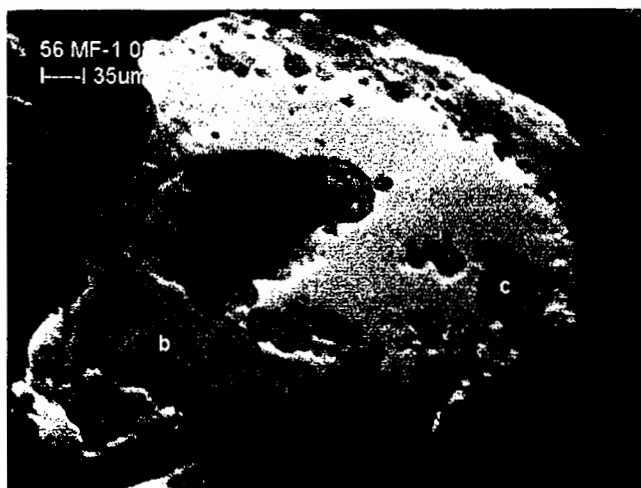
76 blk 01 Fe,Al silicate with trace Cr in soft matrix. "b" = quartz.

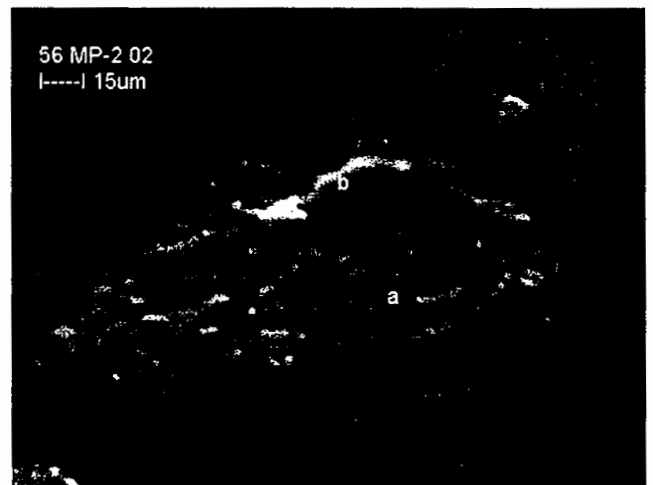
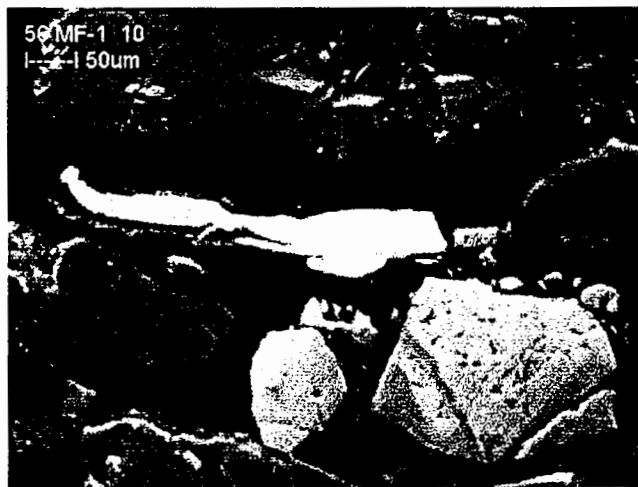
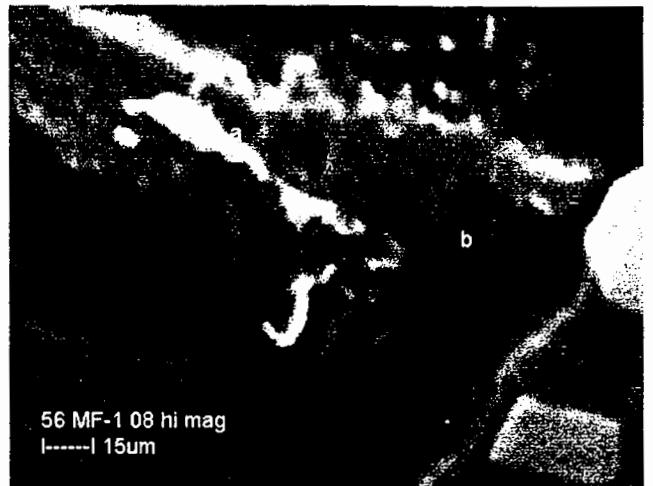
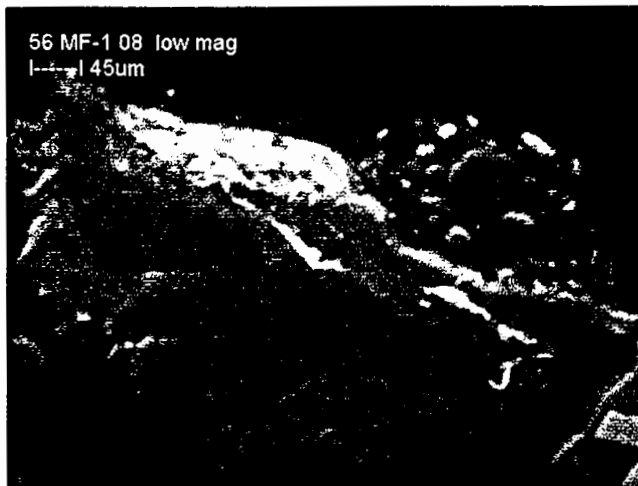
981823 - 77 - < 0.07 Bulk -----
A few grains of titanomagnetite with trace chromium were found.

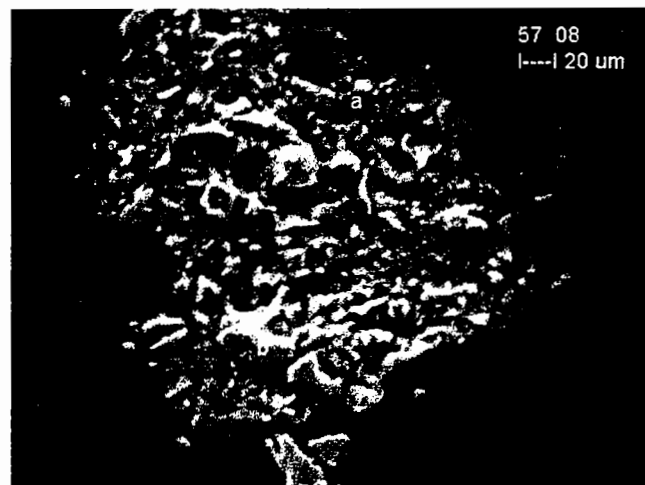
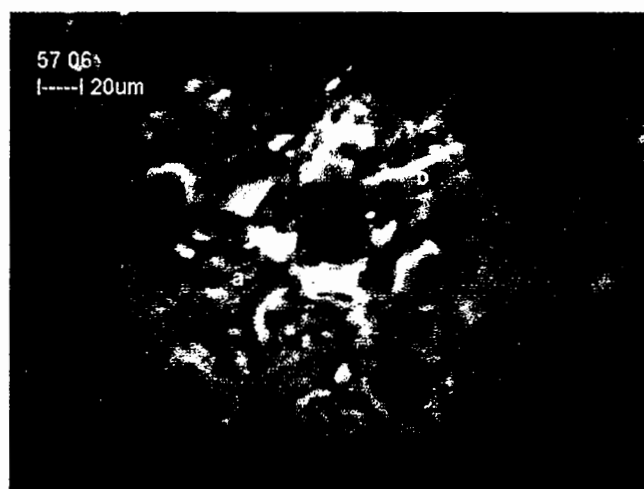
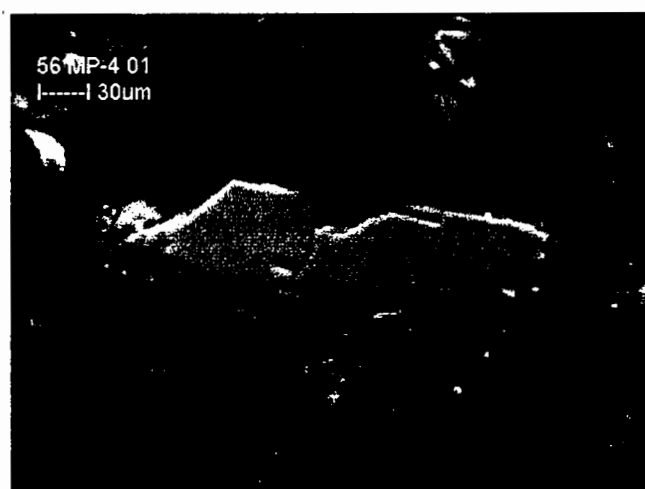
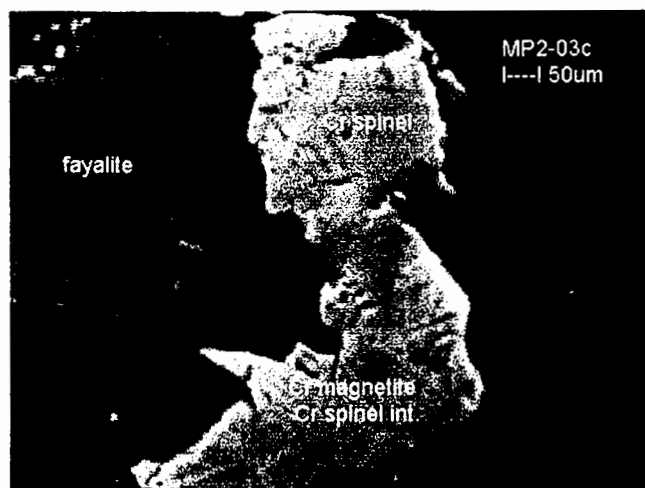
<i>WDS</i>	Cr2O3	MnO	BaO	FeO
77 blk 01 Fe,Al silicate	0.02	0.2	nd	~11.0
77 blk 02 Fe,Al silicate	0.02	0.4	nd	~14.0

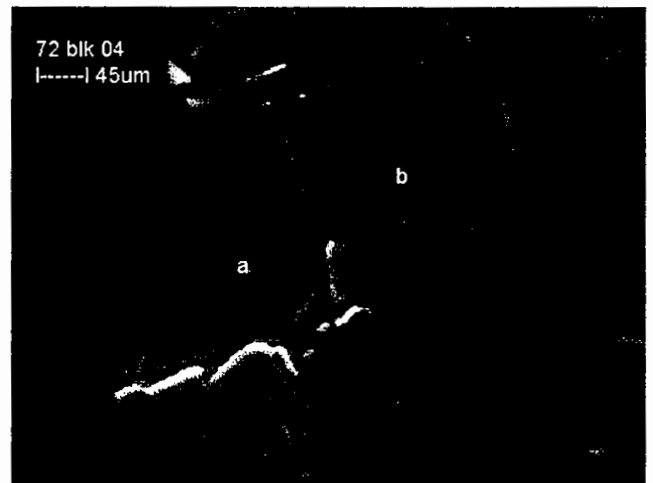
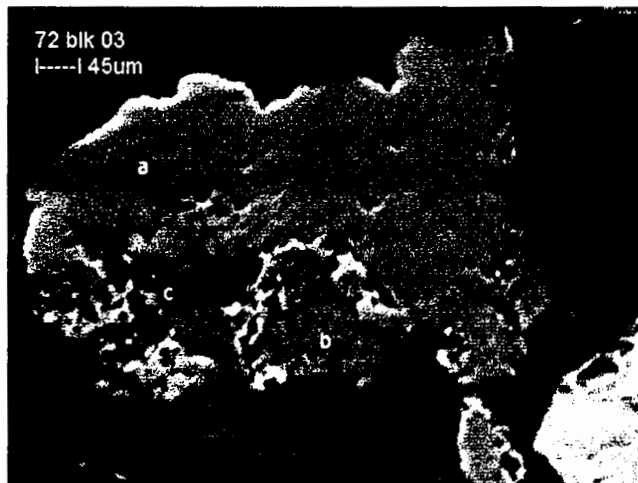
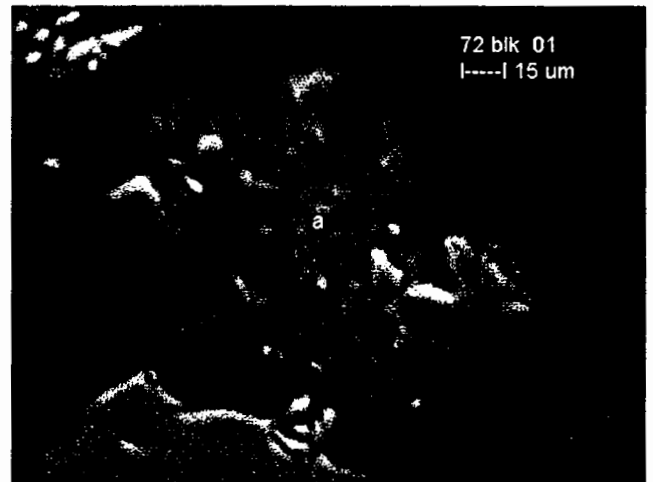
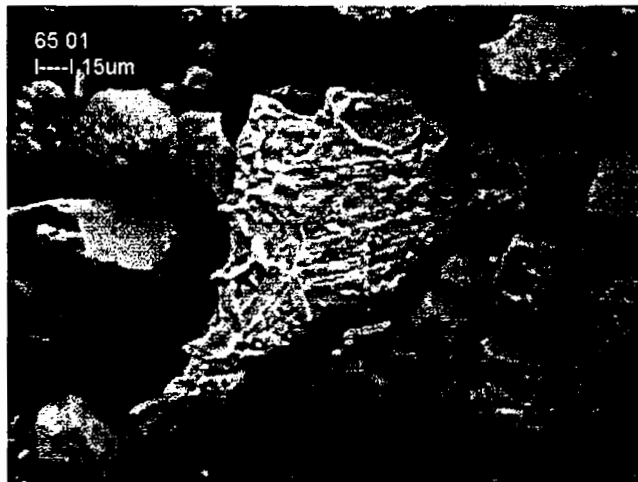
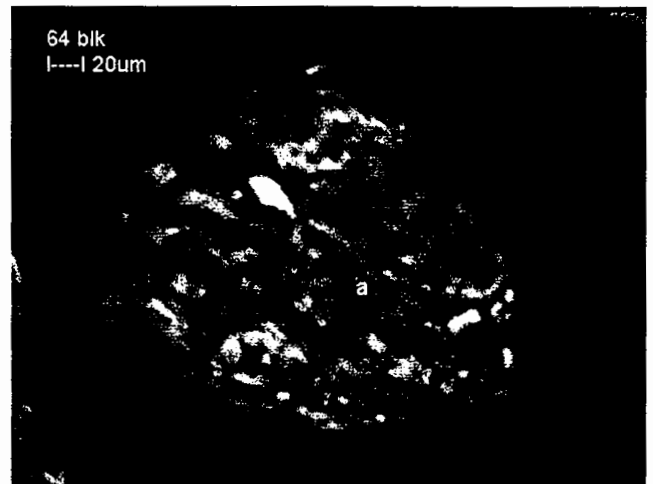
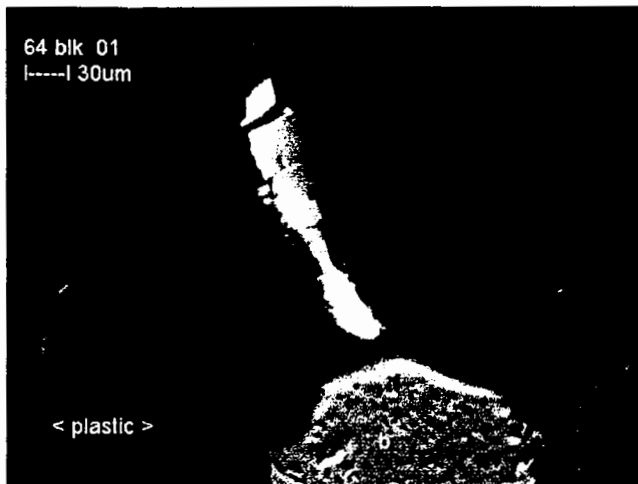


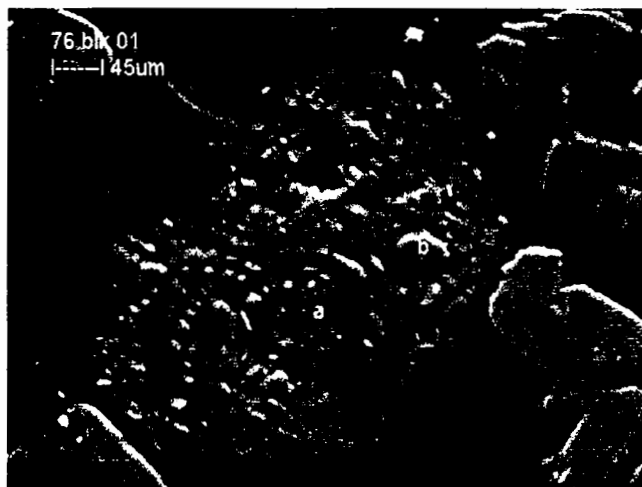
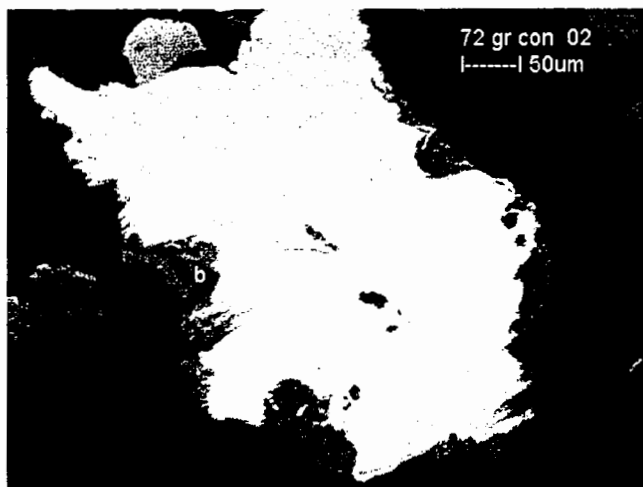
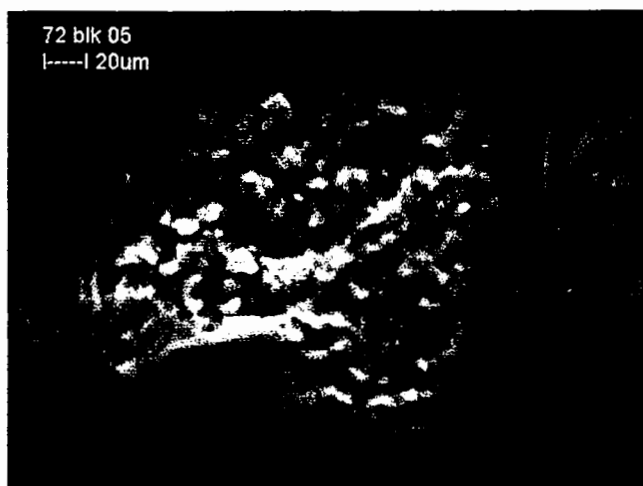


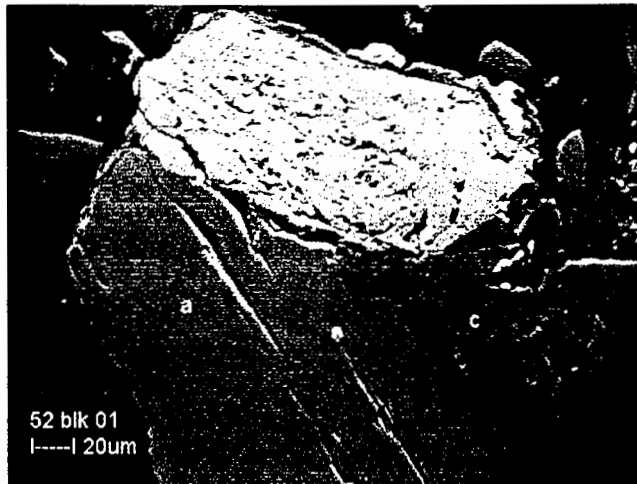






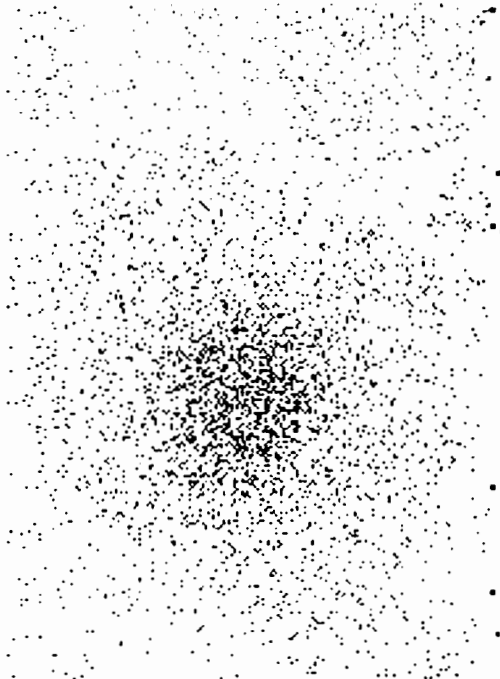




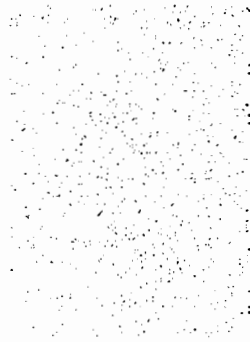




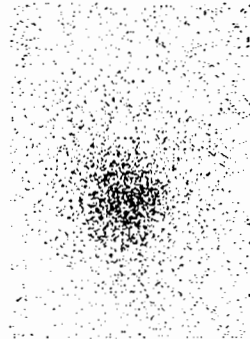
52 bulk 03 BSE image CORRODED IRON



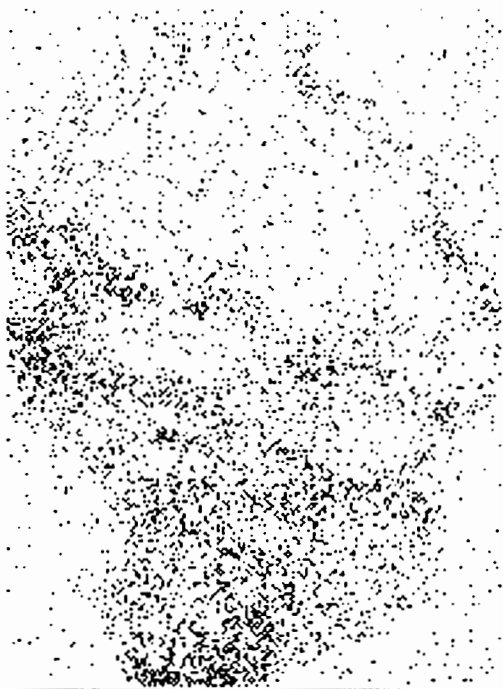
CHROMIUM and MANGANESE



MANGANESE



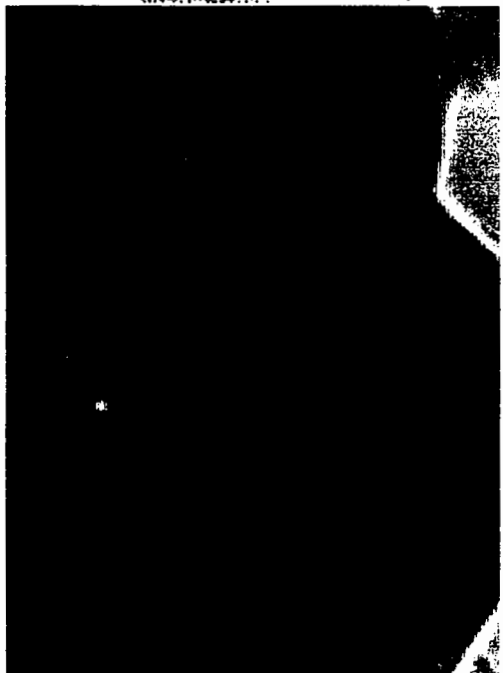
CHROMIUM



MANGANESE and CHROMIUM



CHROMIUM



56 BULK Fe, Al SILICATE



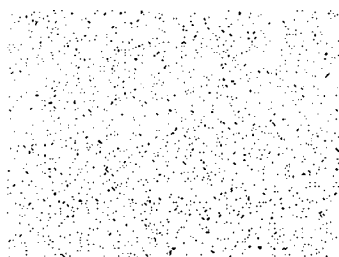
MANGANESE



BACKSCATTERED ELECTRON IMAGE 72 BULK 02 FeAl SILICATE



CHROMIUM and MANGANESE



MANGANESE

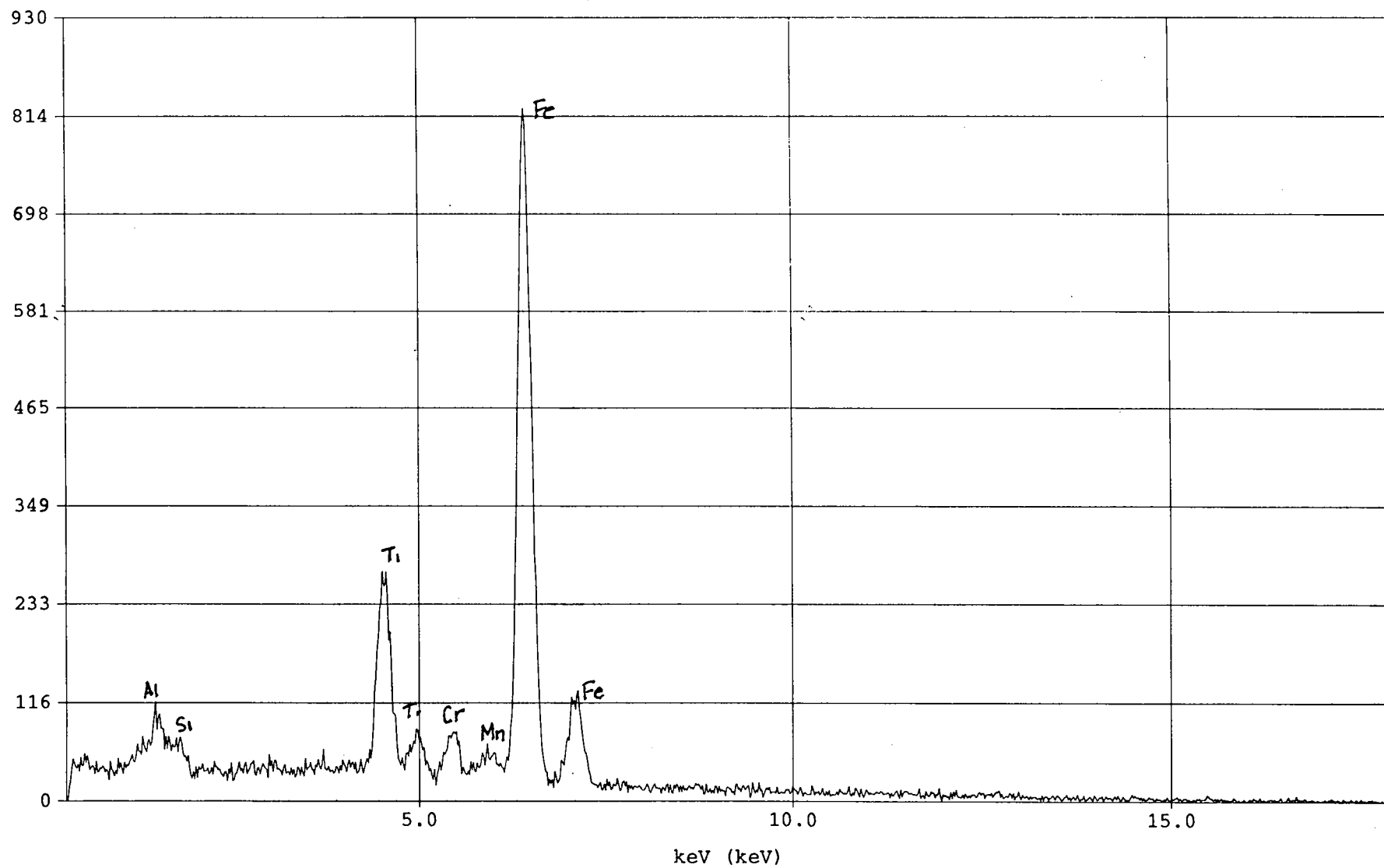


CHROMIUM

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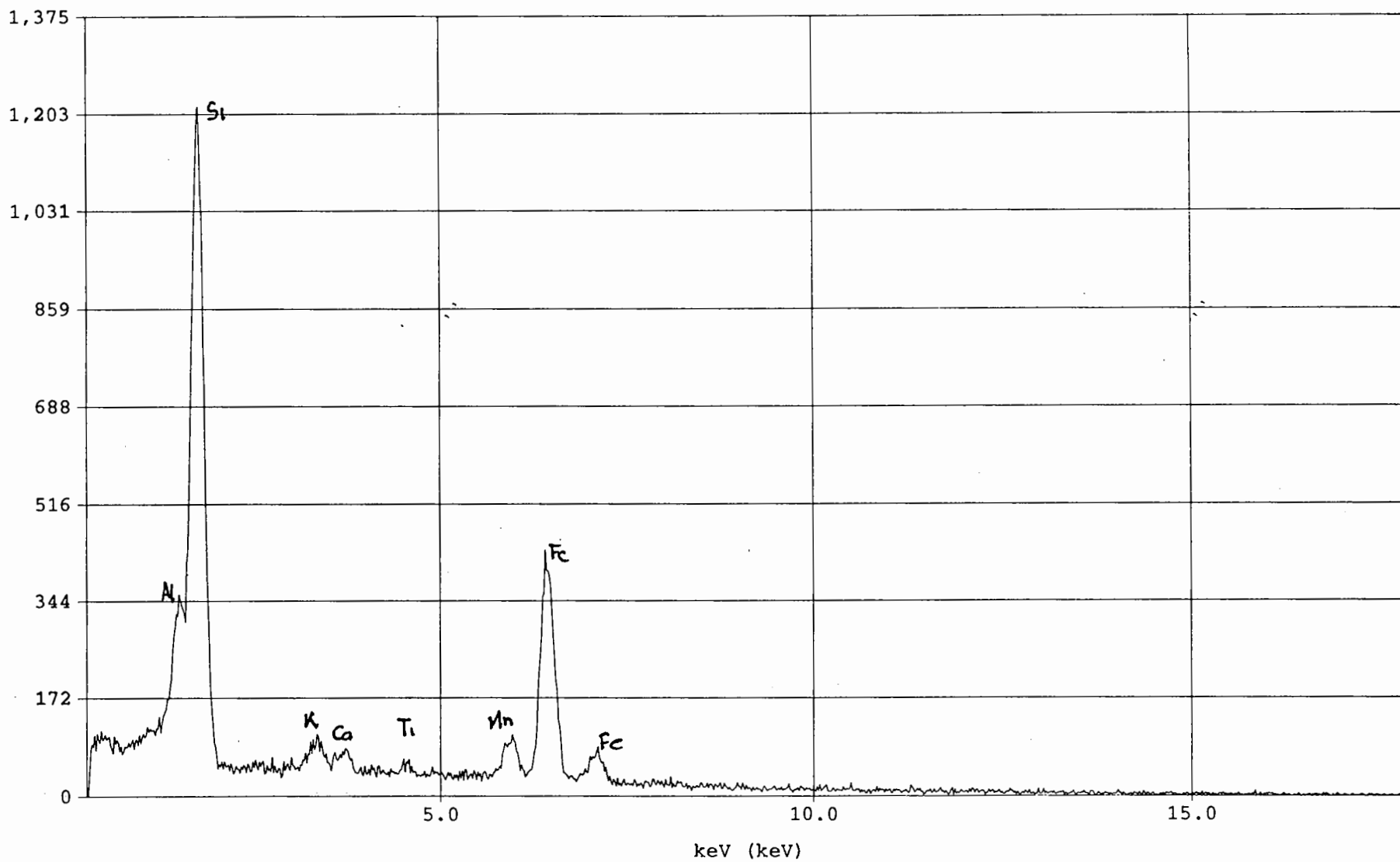
ID(1): # 52 CONCENTRATE 04



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Spectrum Plot Routine

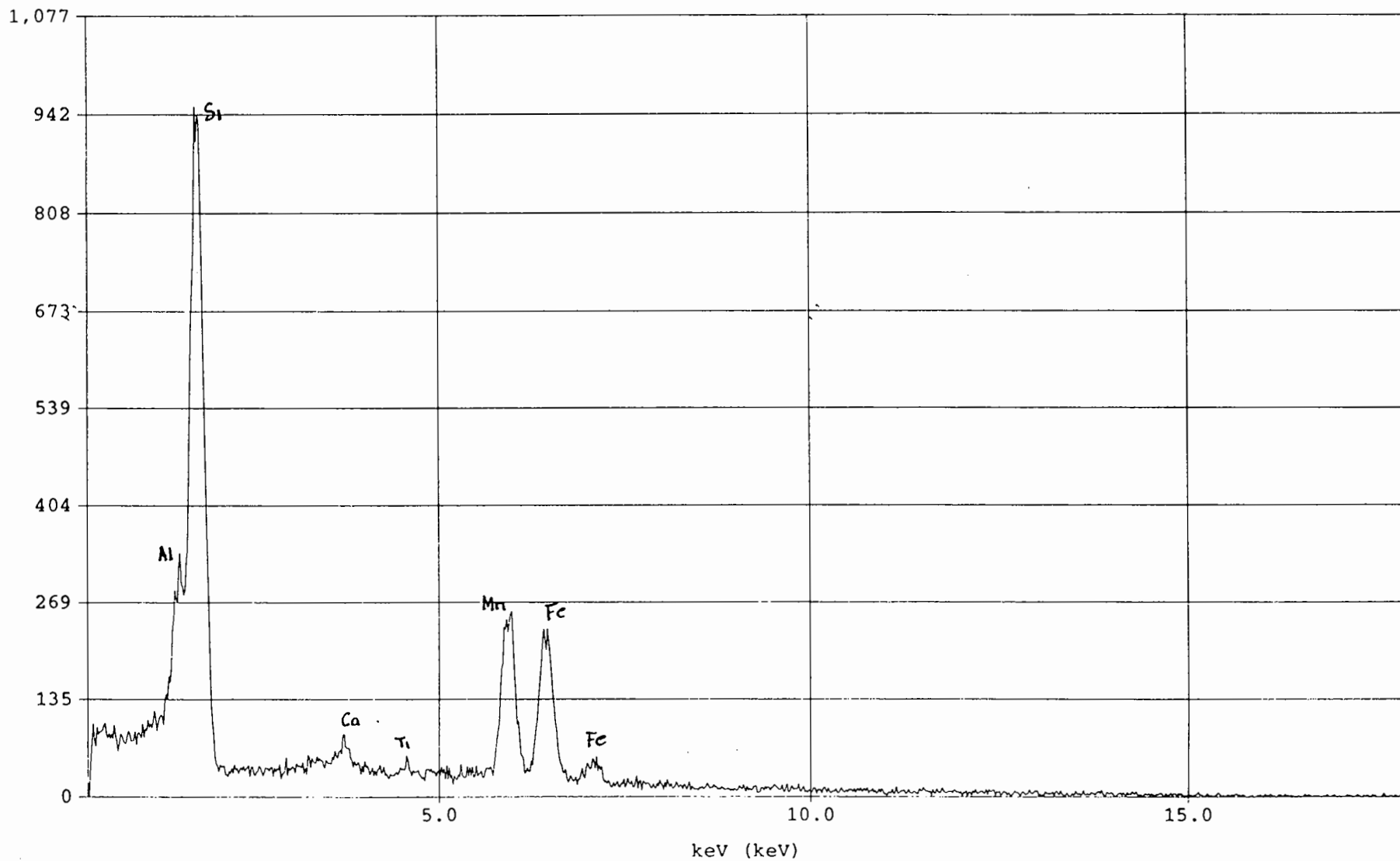
ID(1): # 56 06



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Spectrum Plot Routine

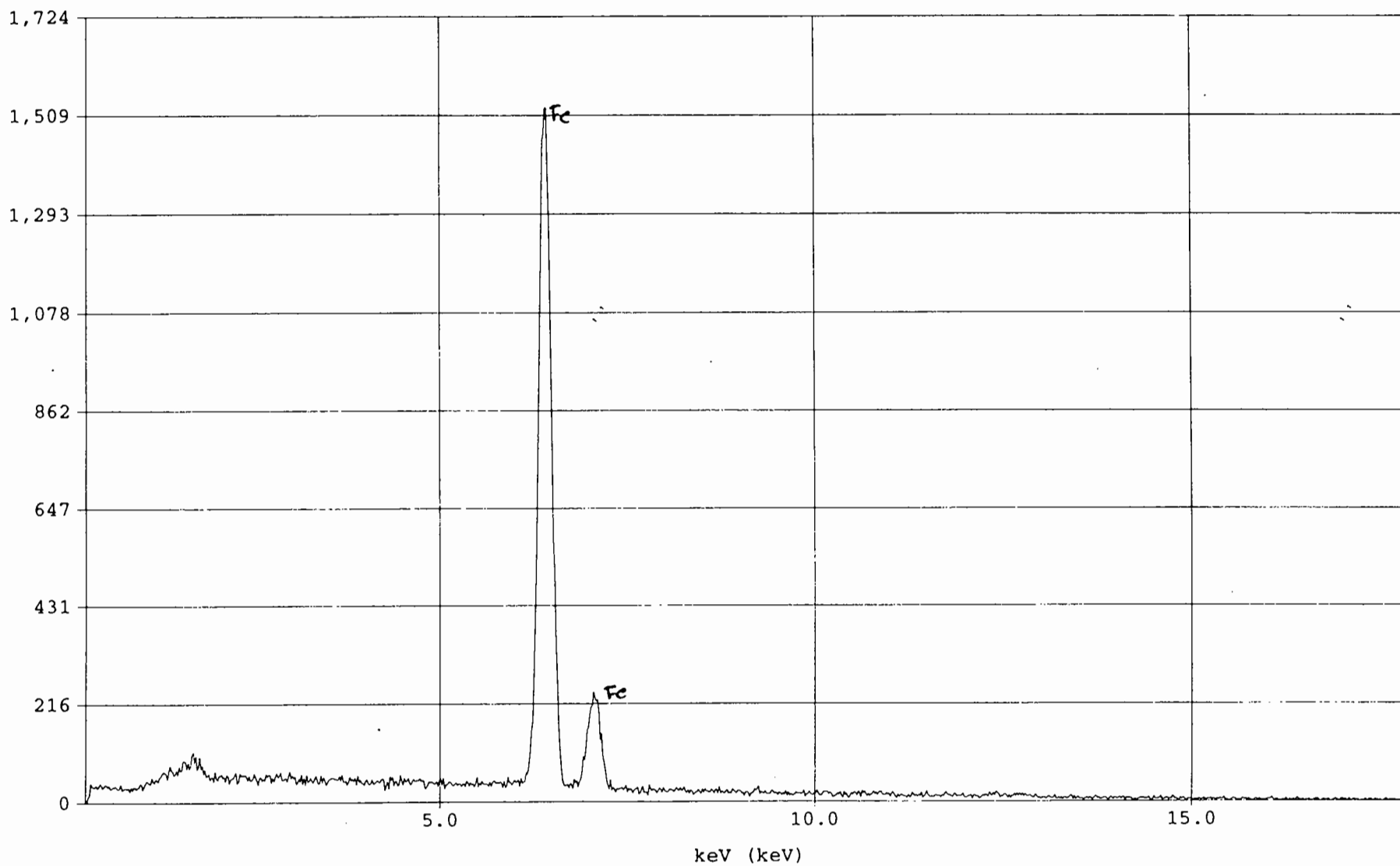
ID(1): # 56 07



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Spectrum Plot Routine

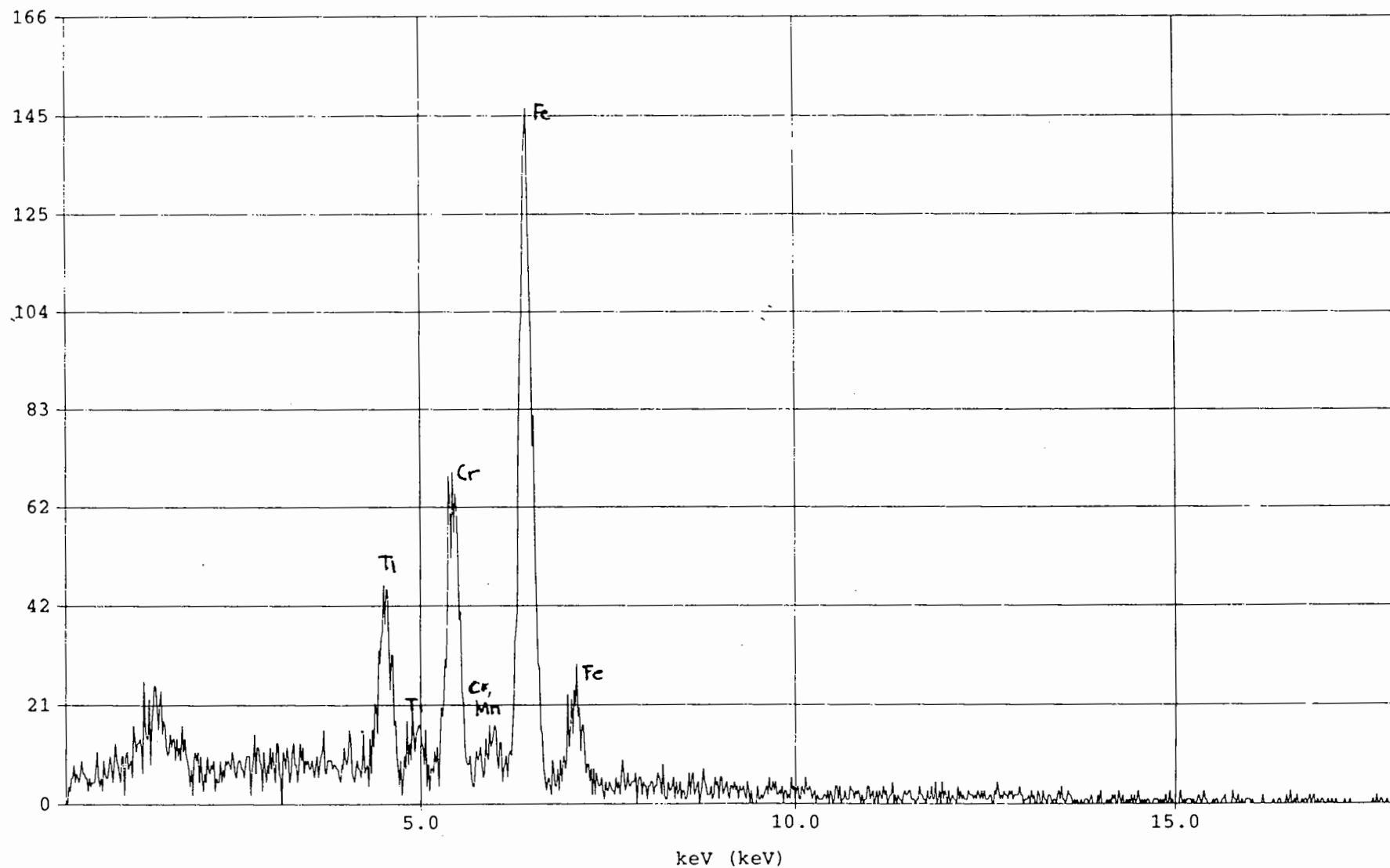
ID(1): # 56 GRAVITY CONCENTRATE 01



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Spectrum Plot Routine

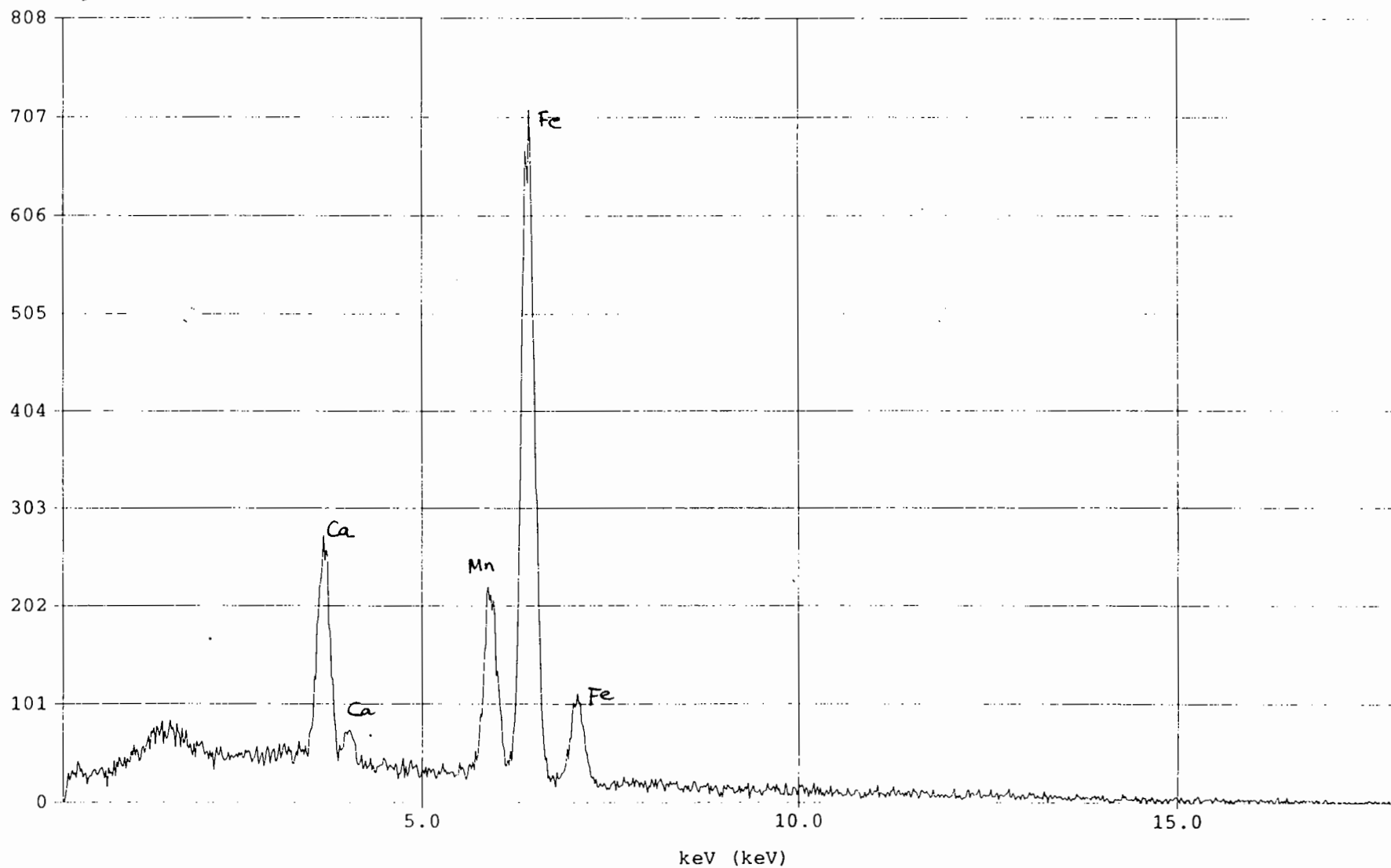
ID(1): # 56 GRAVITY CONCENTRATE 011



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Spectrum Plot Routine

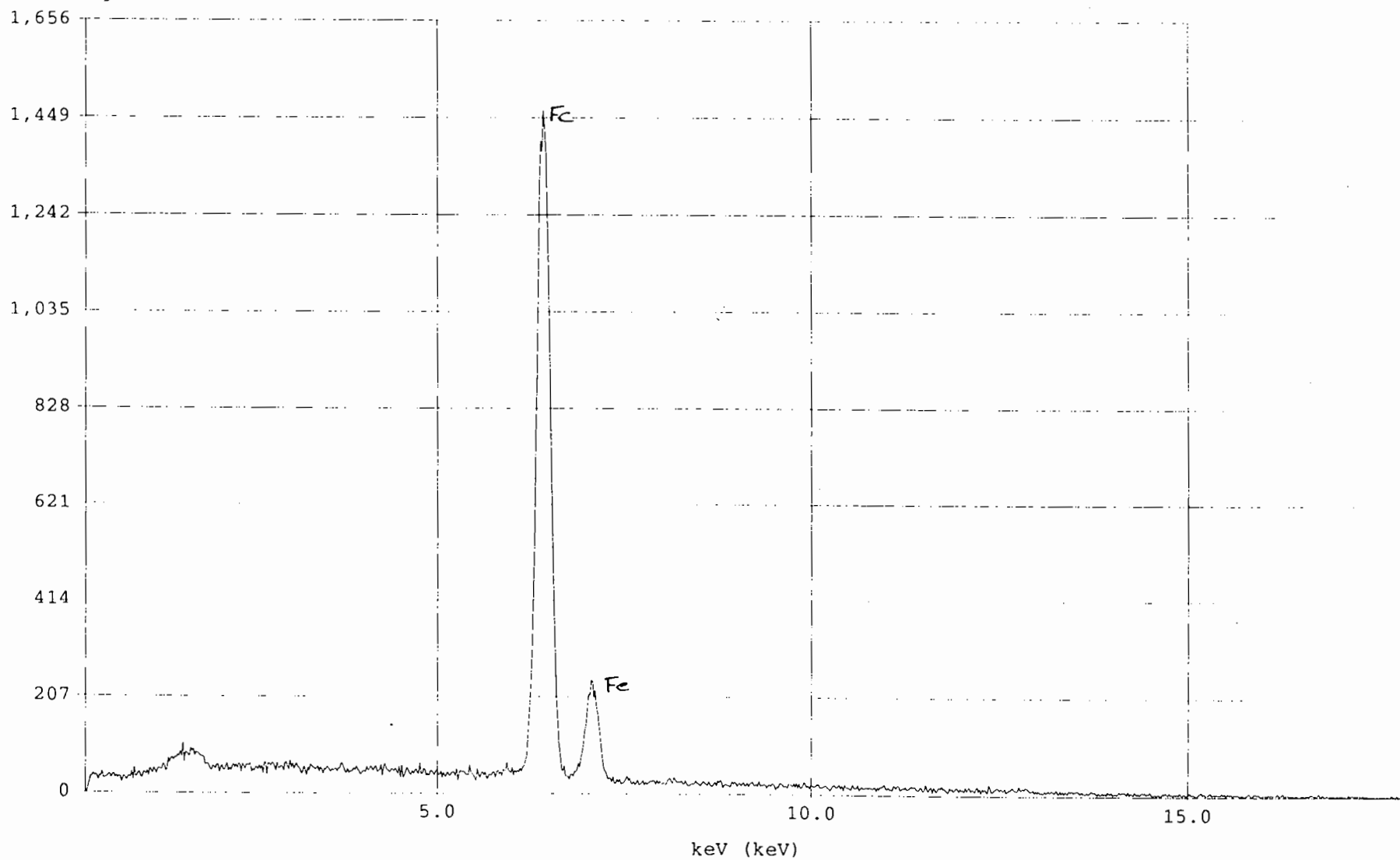
ID(1): # 52 gr con 02a



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Spectrum Plot Routine

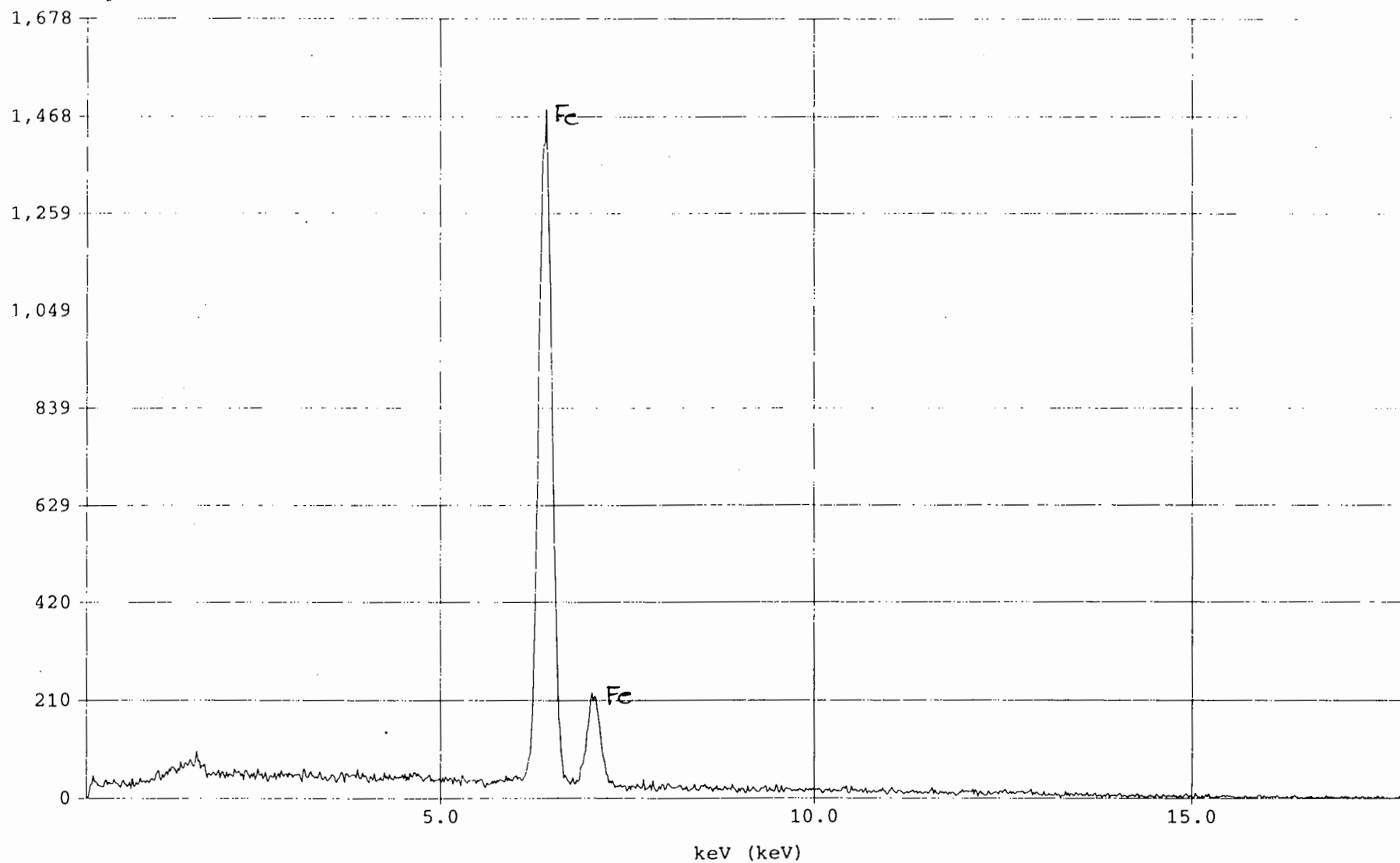
ID(1): # 52 gr con 02b



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Spectrum Plot Routine

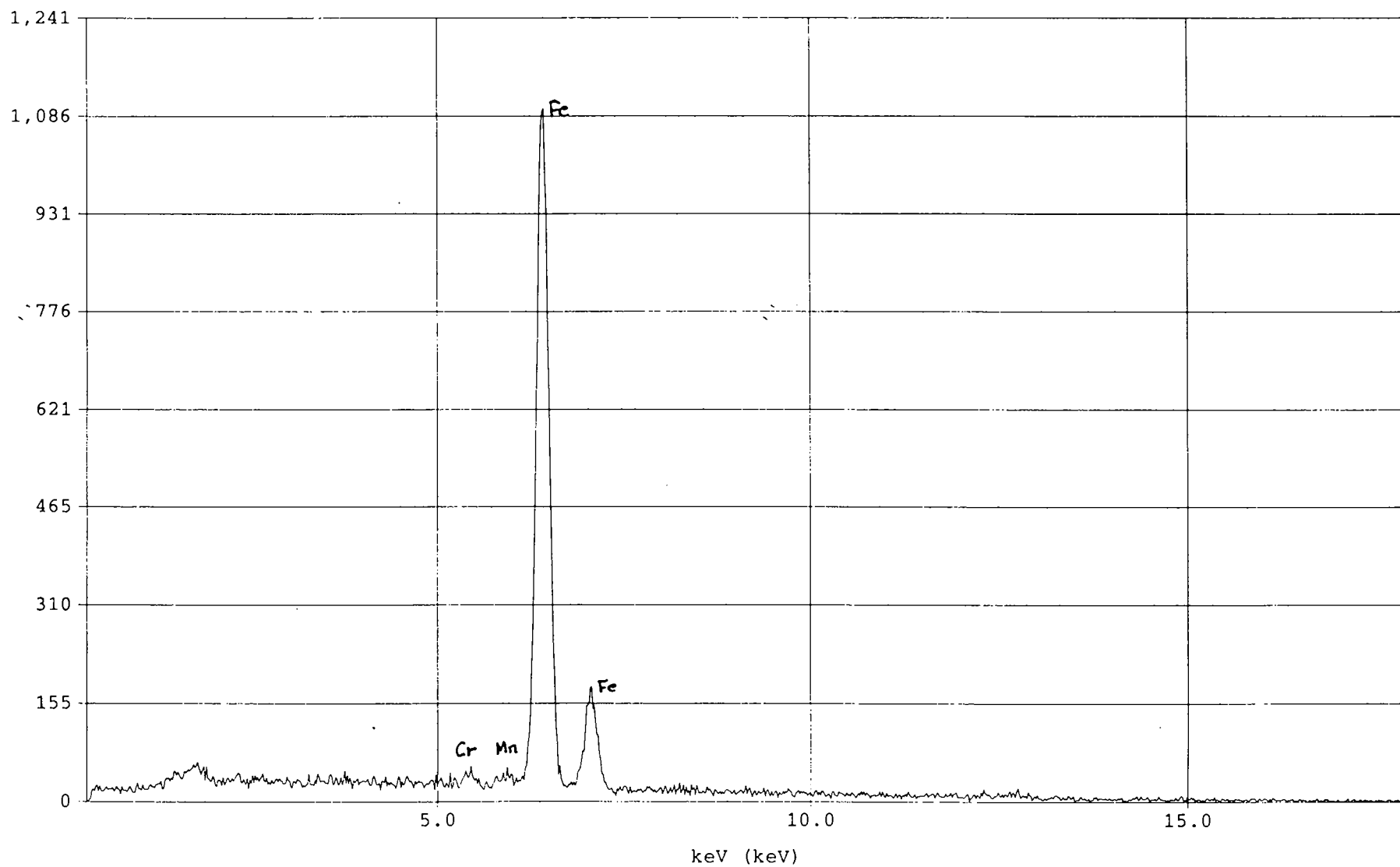
ID(1): # 52 gr con 02c



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Spectrum Plot Routine

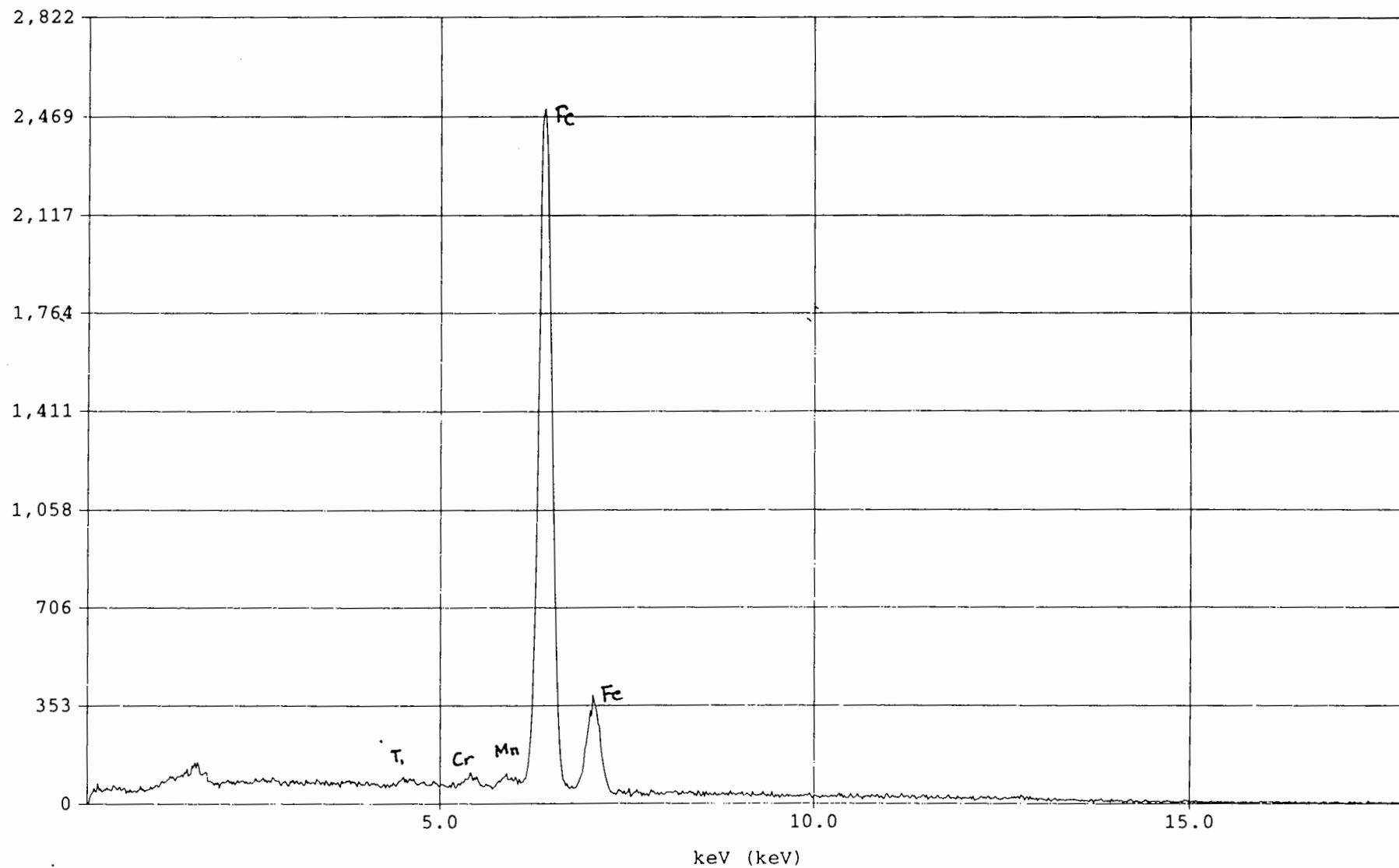
ID(1): MF 1 01



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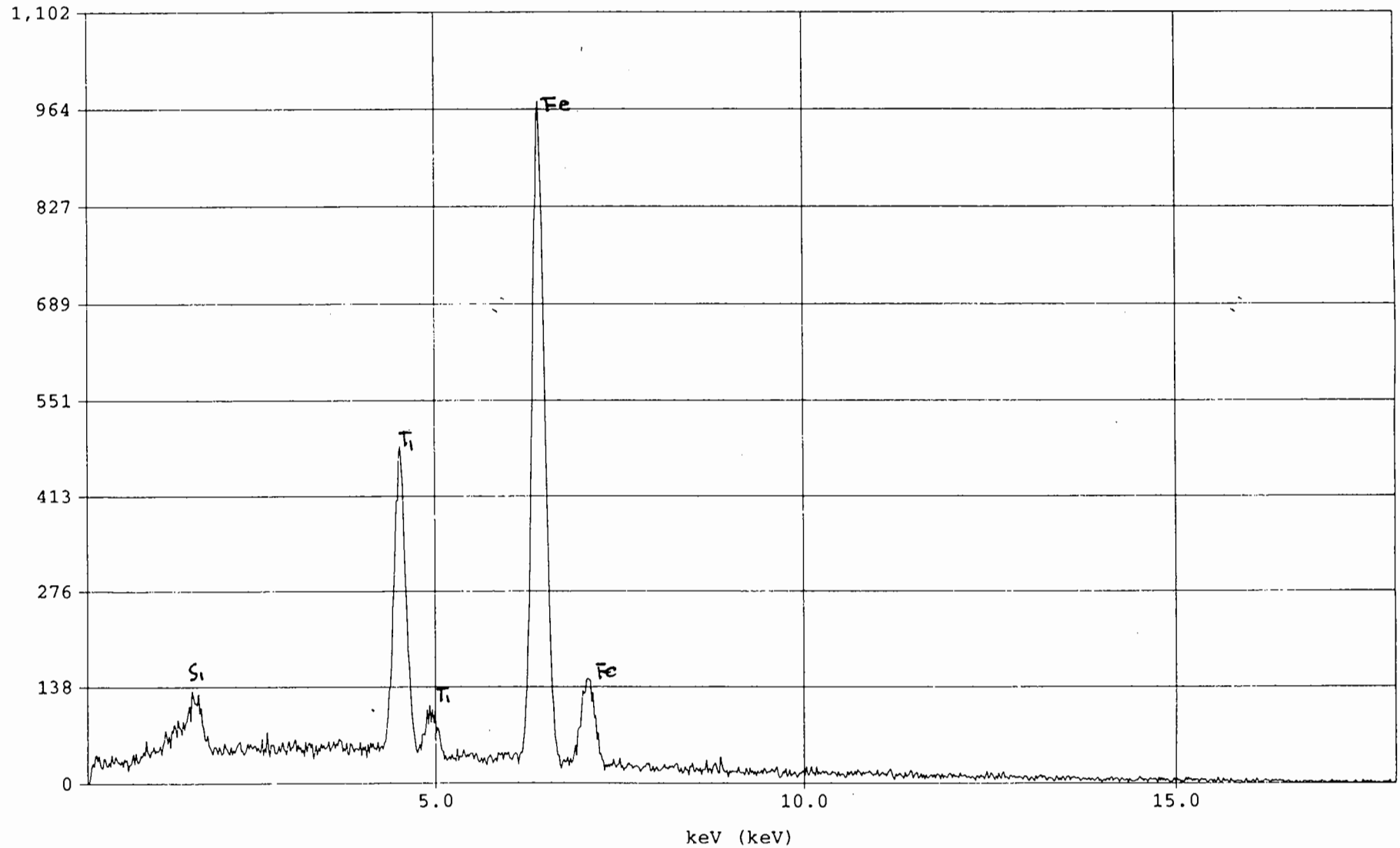
ID(1): MF 1 05 2



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Spectrum Plot Routine

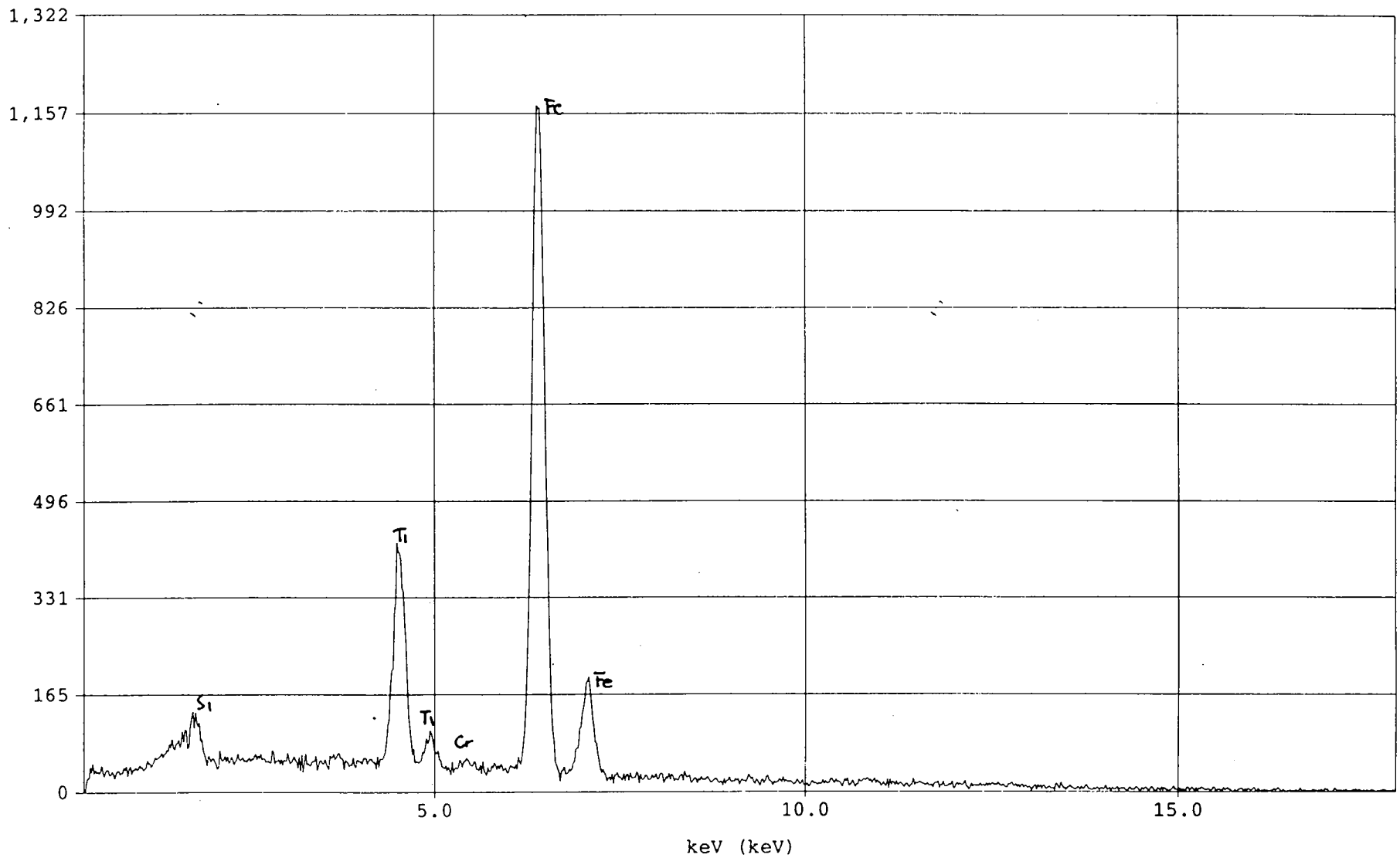
ID(1): MF 1 06 A



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Spectrum Plot Routine

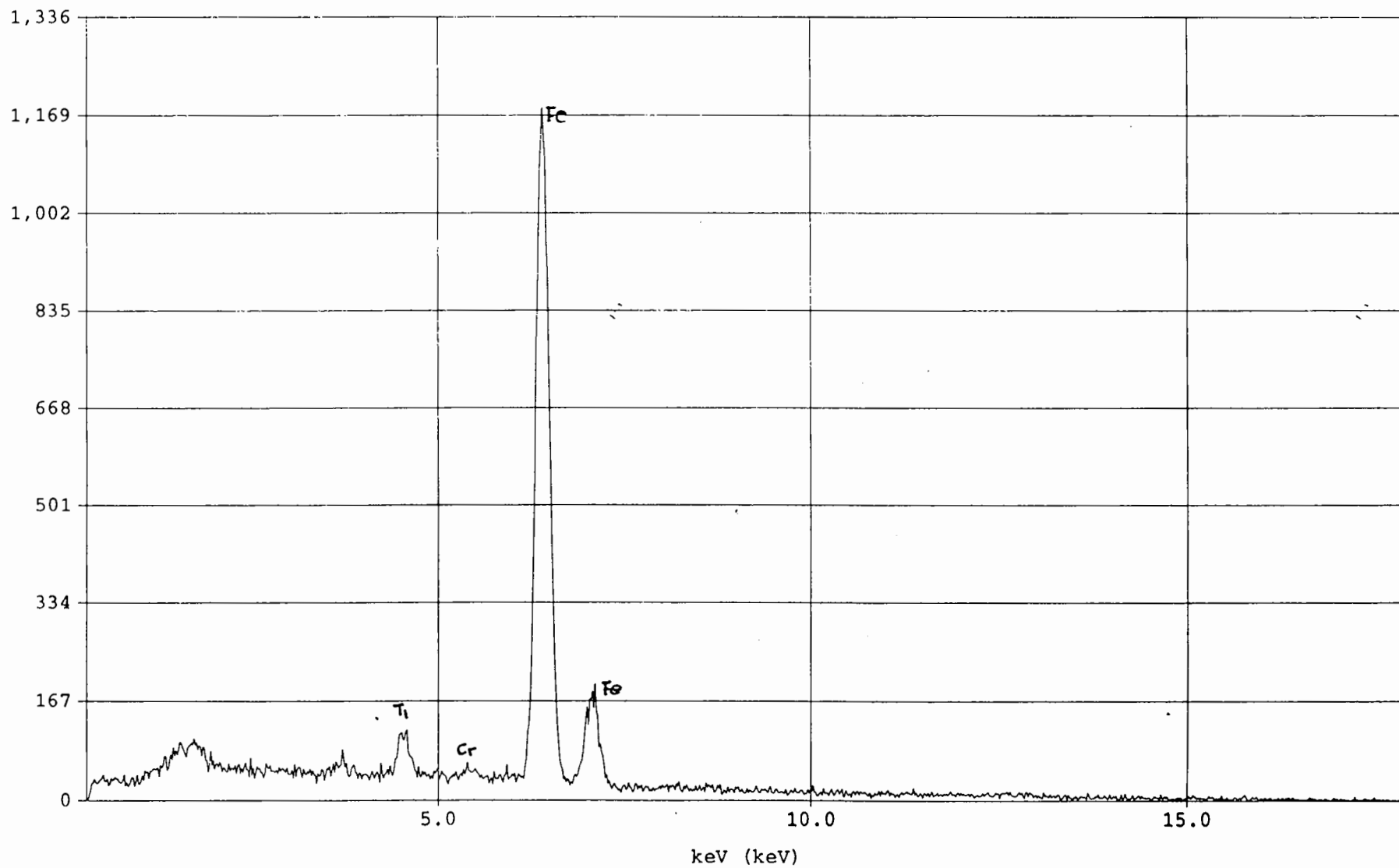
ID(1): MF 1 06 B



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Spectrum Plot Routine

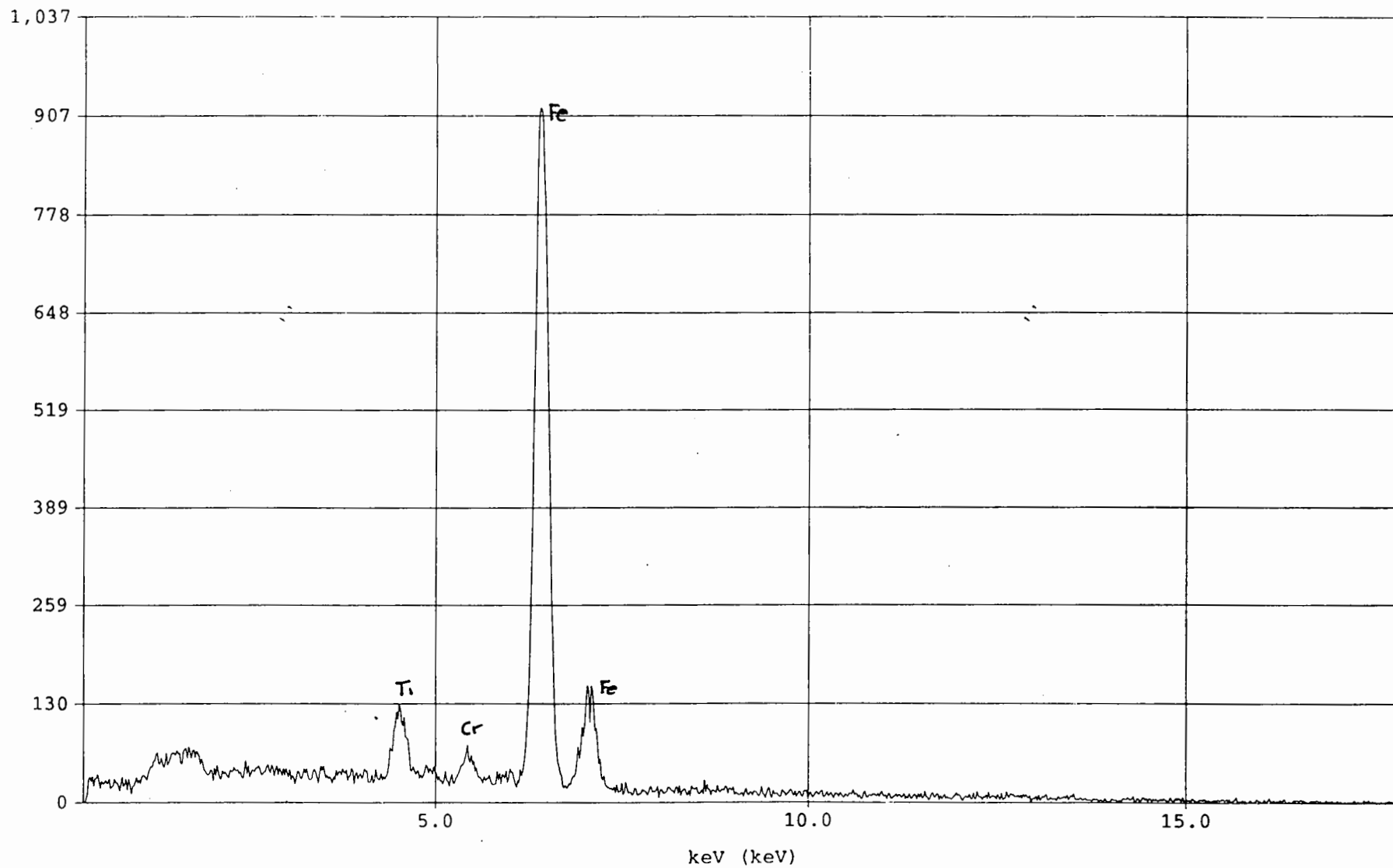
ID(1): MF 1 06 C



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Spectrum Plot Routine

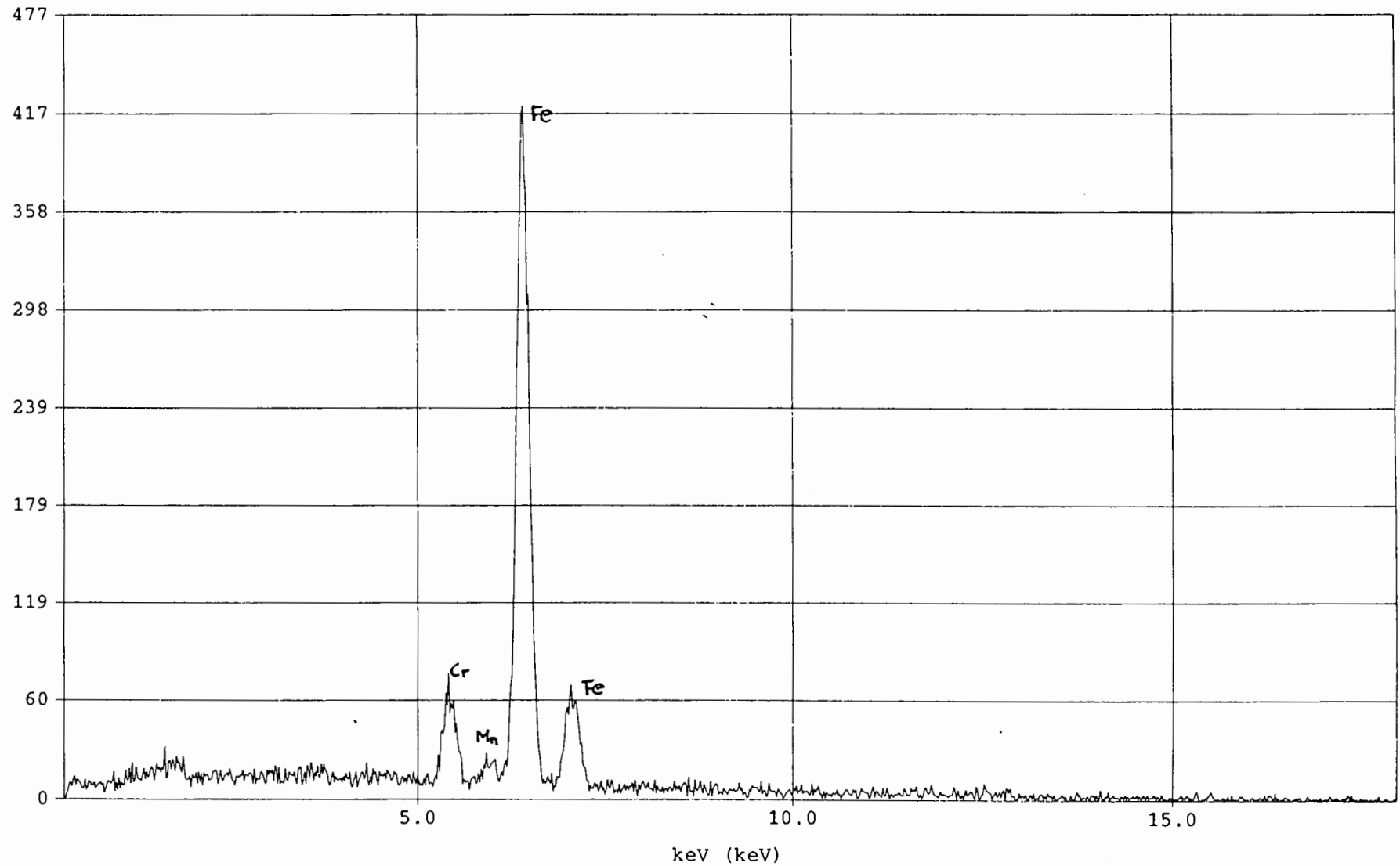
ID(1): MF 1 07



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Spectrum Plot Routine

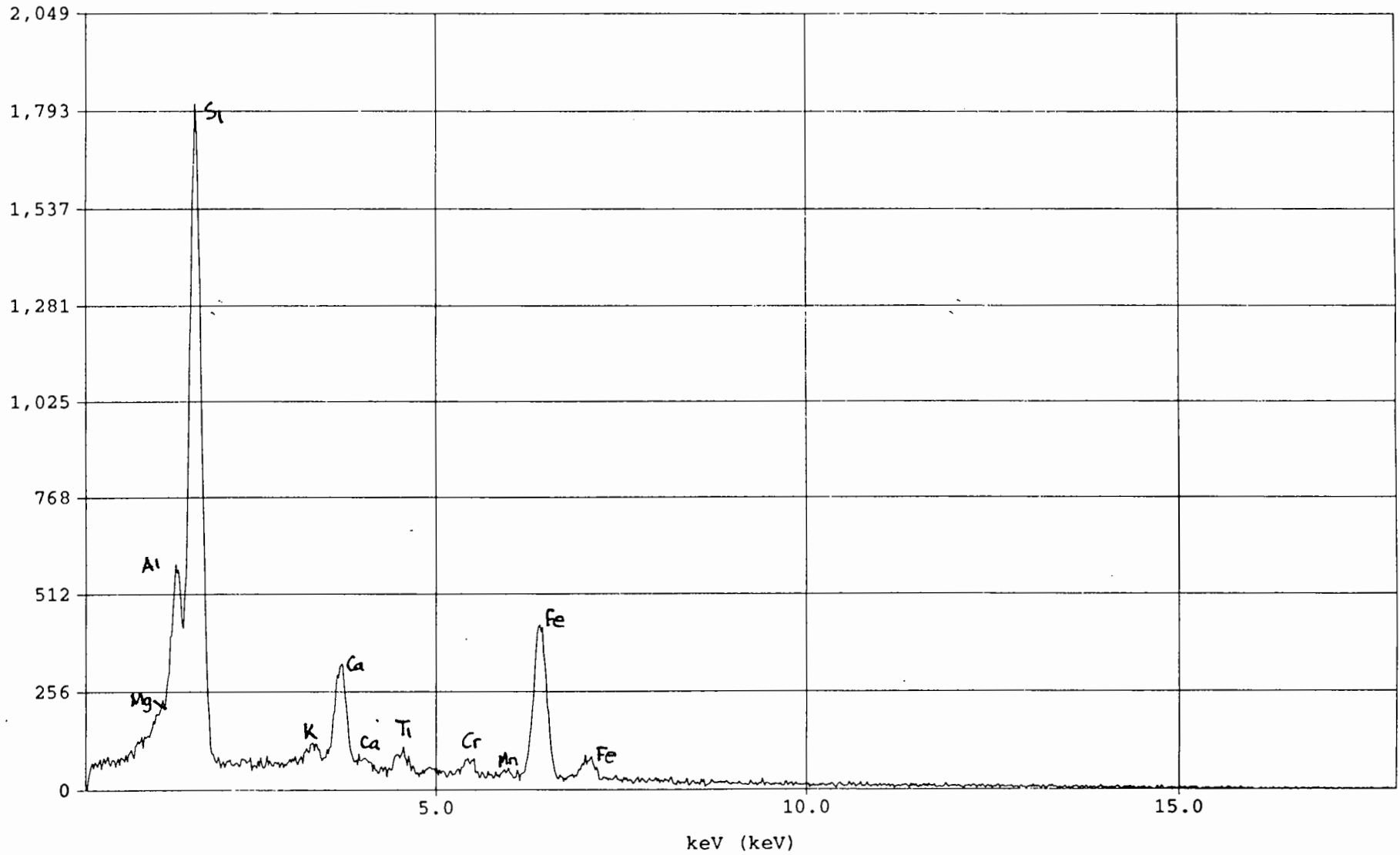
ID(1): MF 1 08 A



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Spectrum Plot Routine

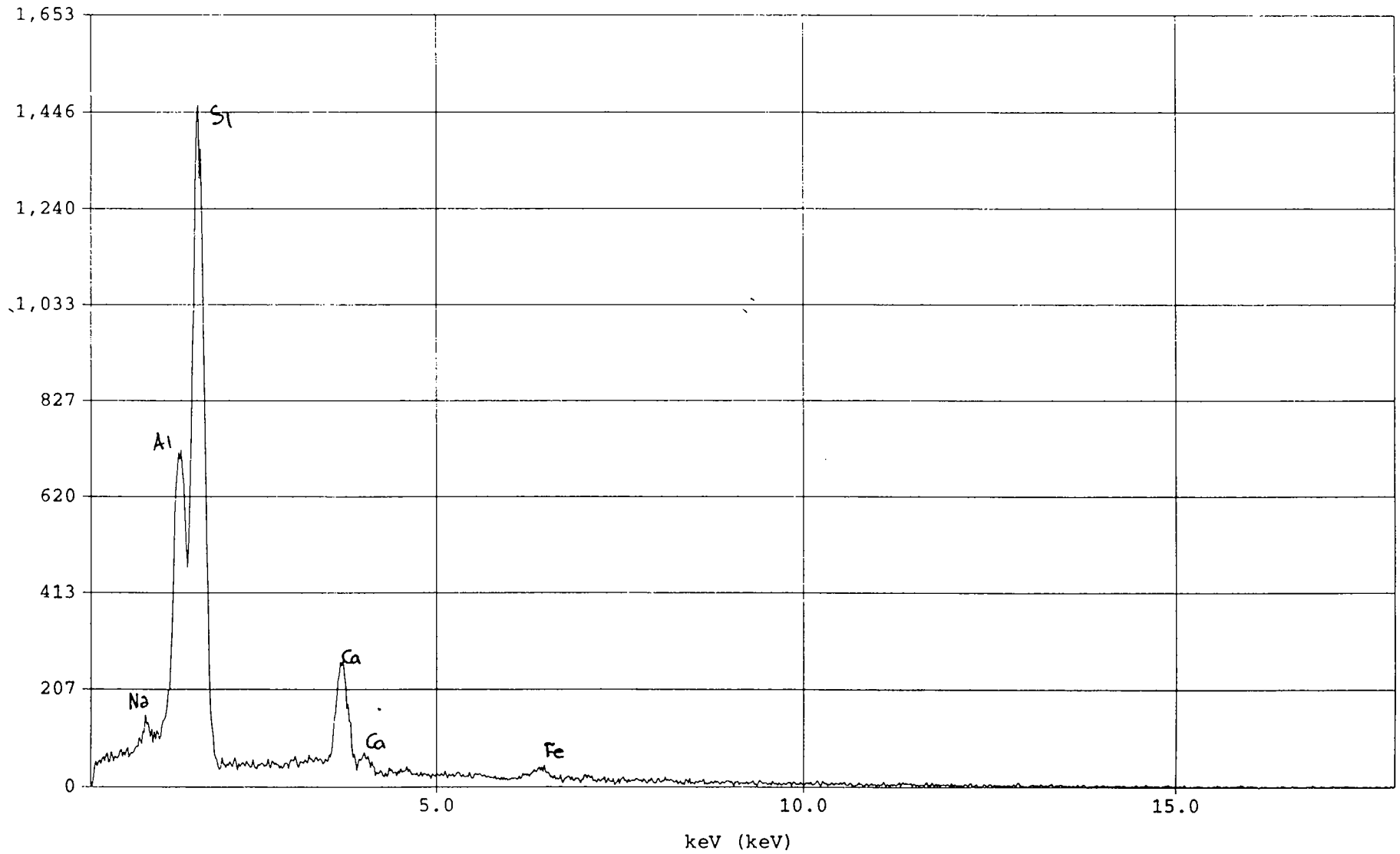
ID(1): MF 108 B



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Spectrum Plot Routine

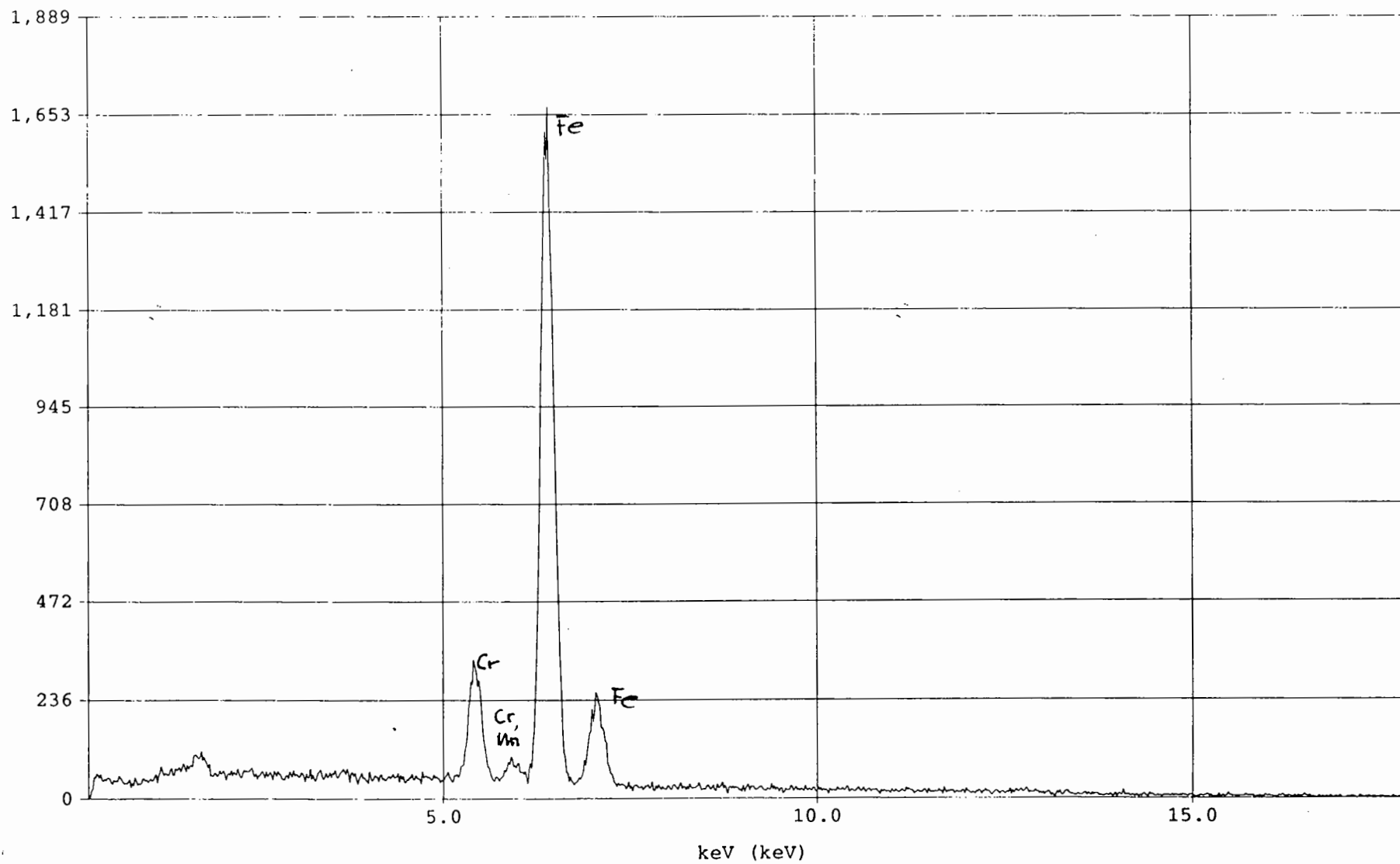
ID(1): MF 1 08 C



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Spectrum Plot Routine

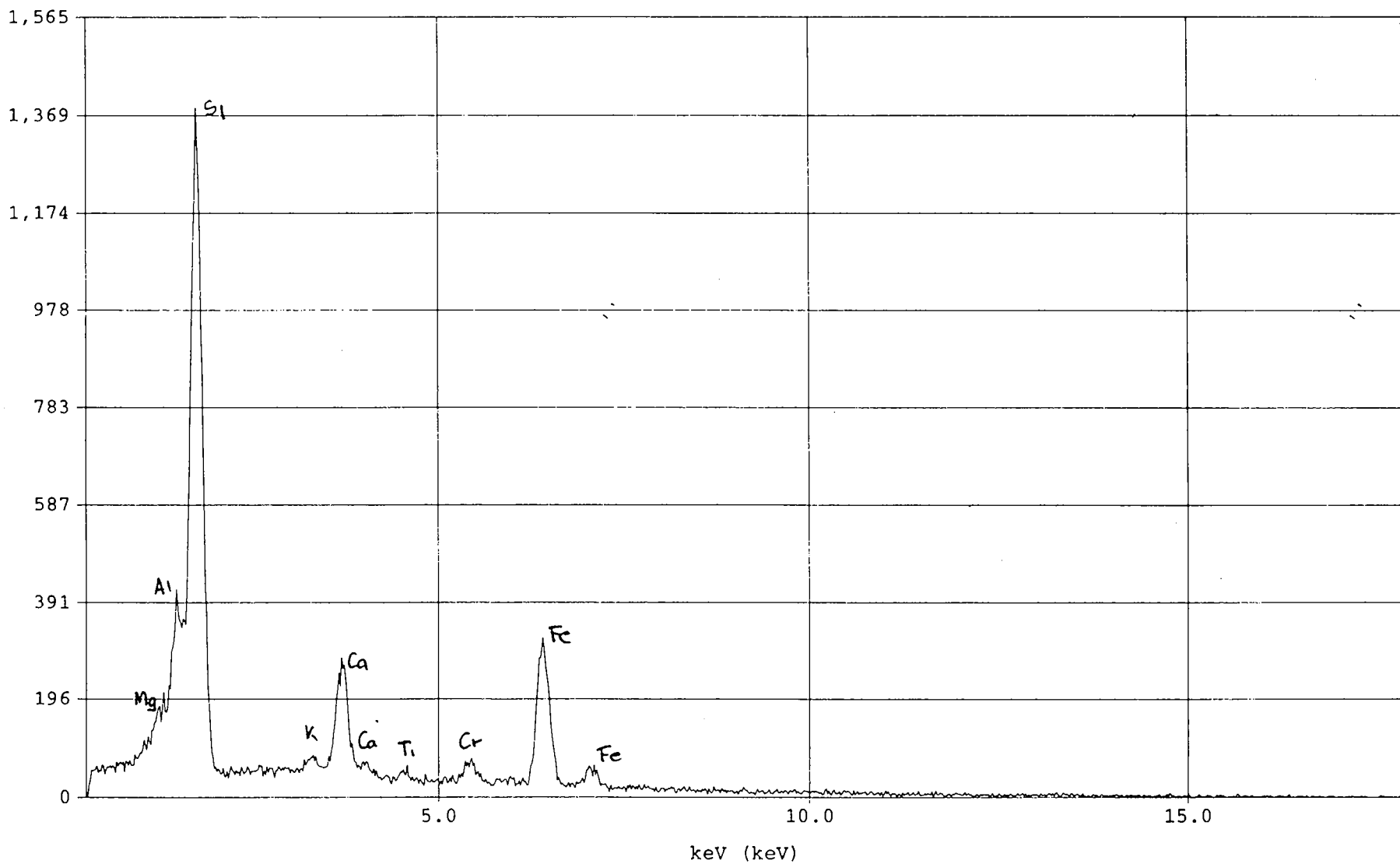
ID(1): MF 109 A



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Spectrum Plot Routine

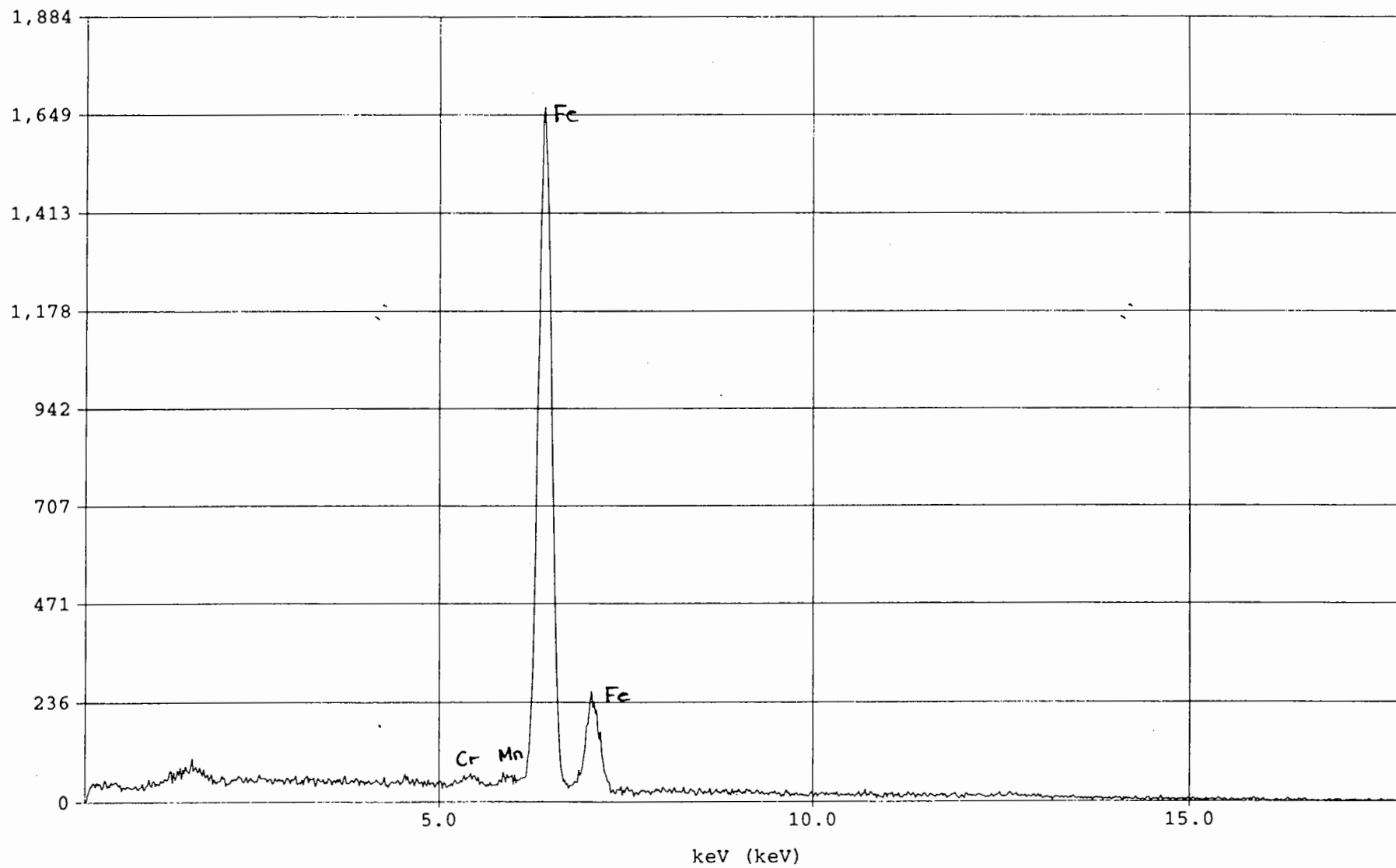
ID(1): MF 1 09 B



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Spectrum Plot Routine

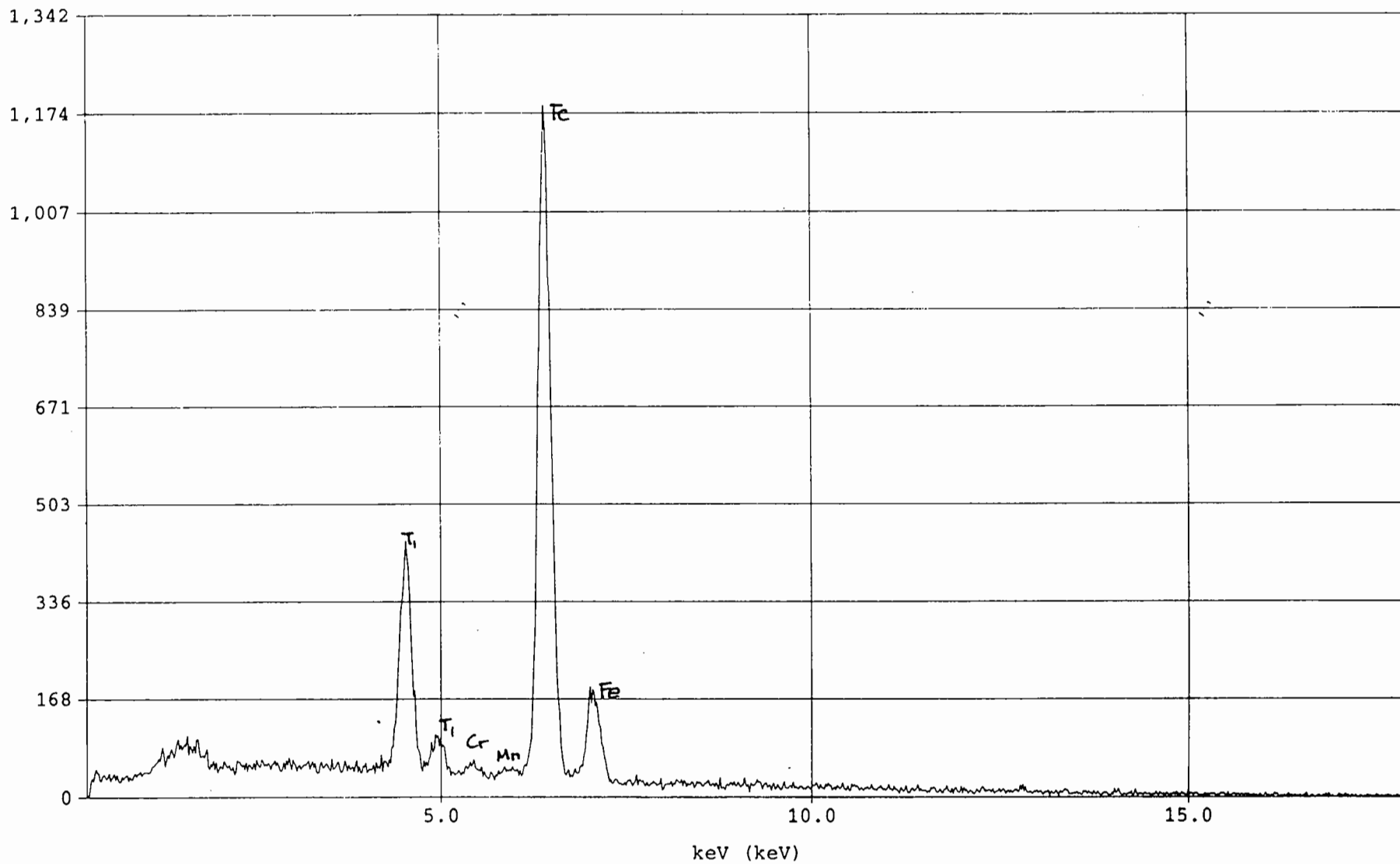
ID(1): MF 1 10



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Spectrum Plot Routine

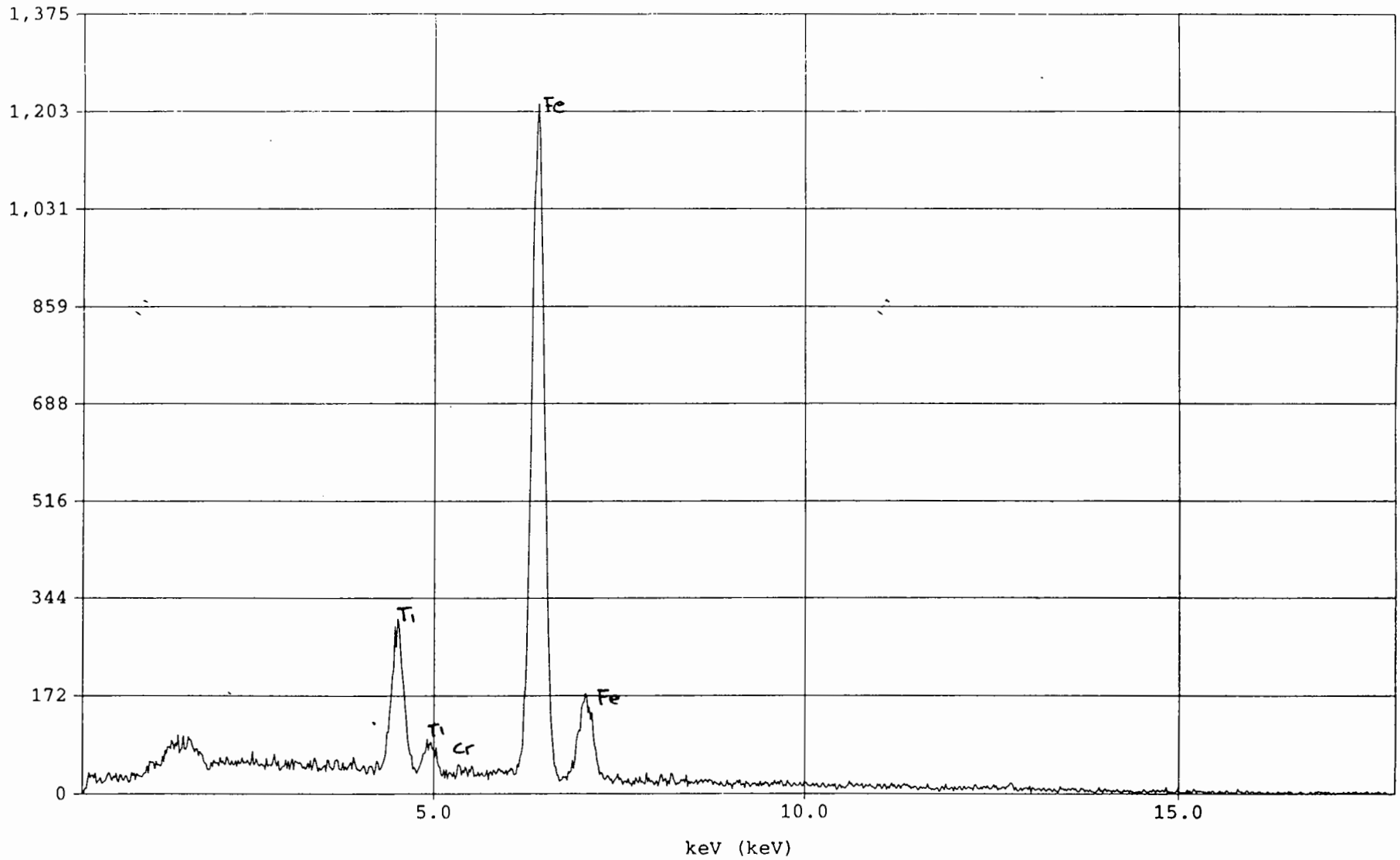
ID(1): MF 2 04



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Spectrum Plot Routine

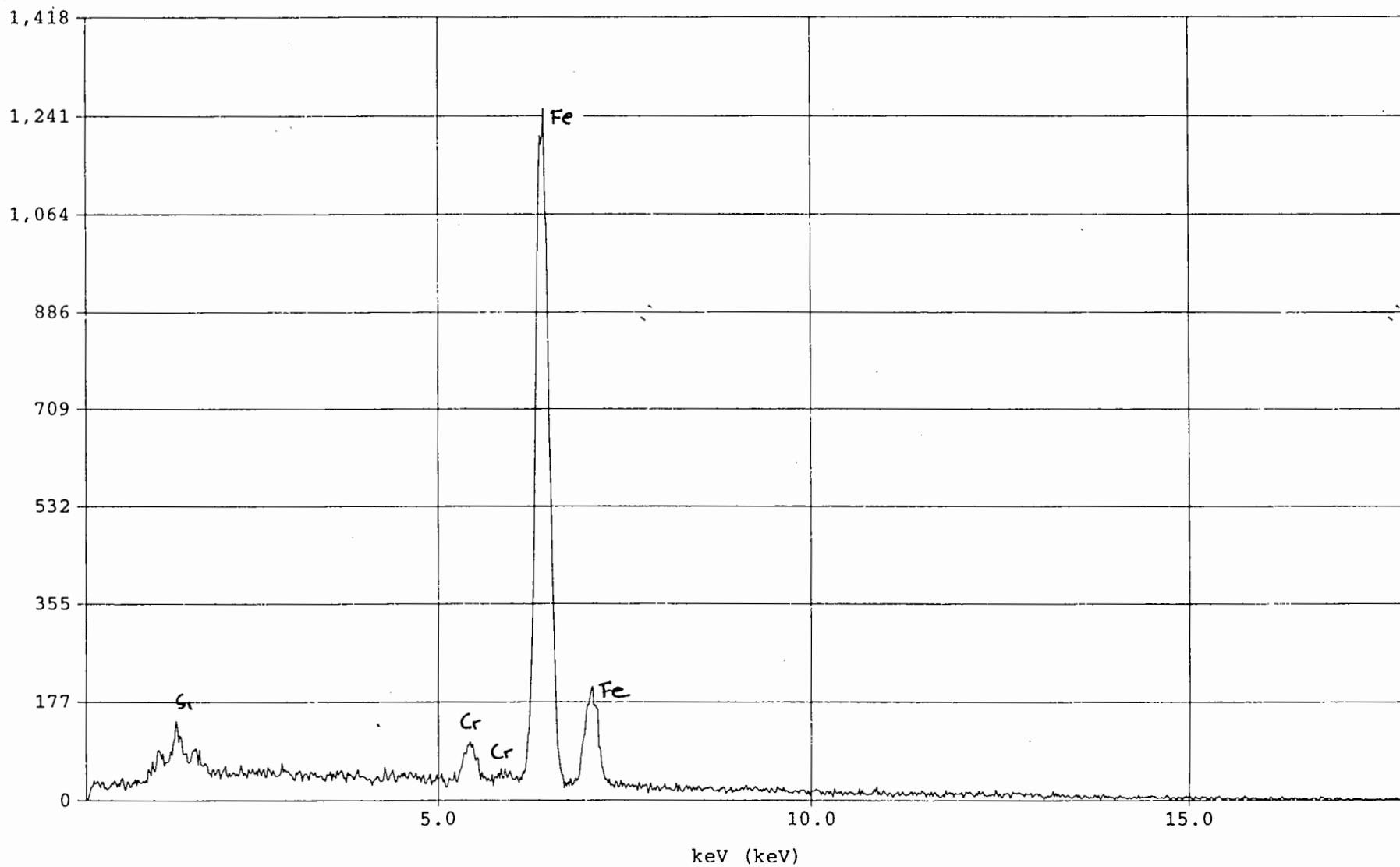
ID(1): MP 2 02



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Spectrum Plot Routine

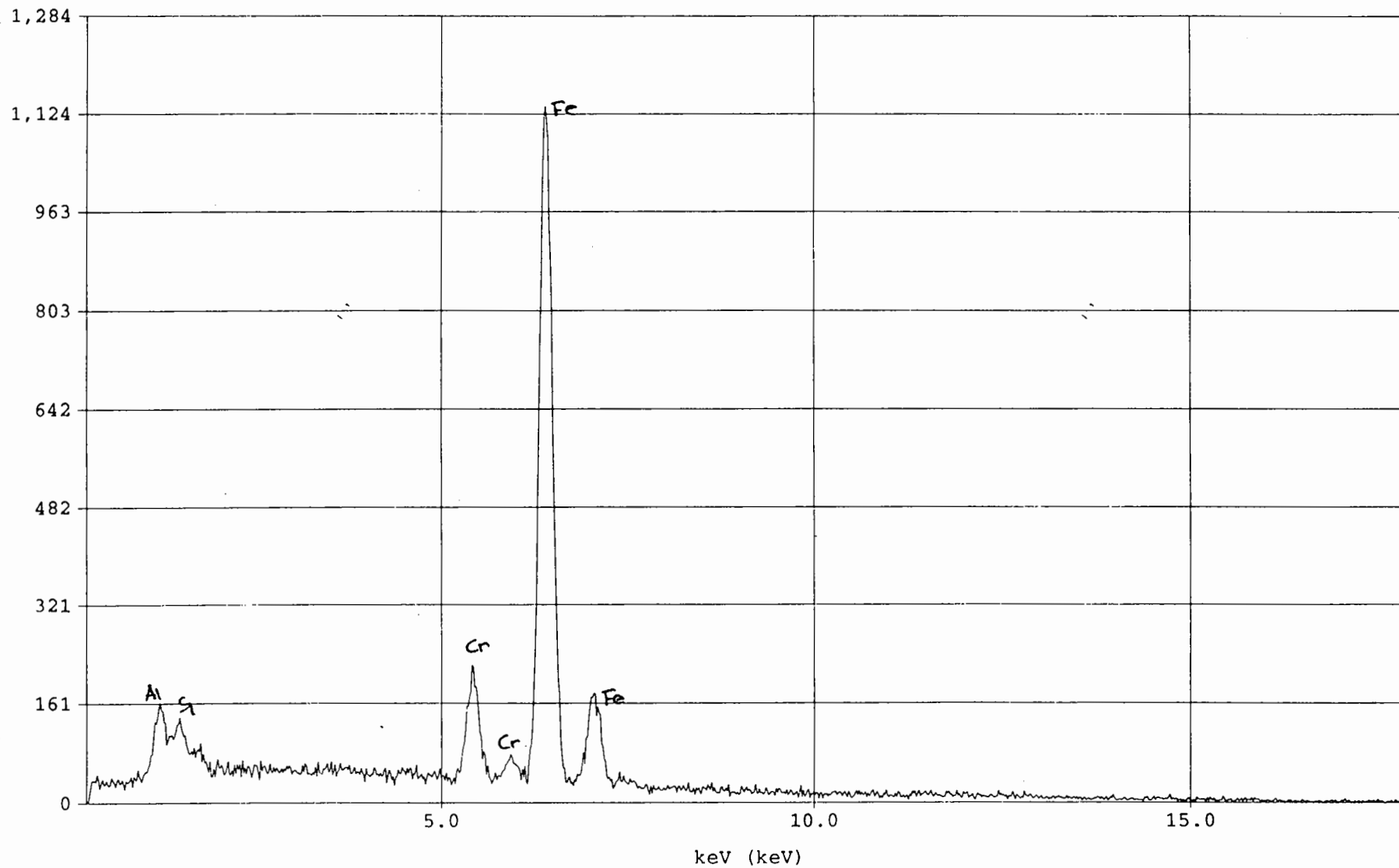
ID(1): MP 203



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Spectrum Plot Routine

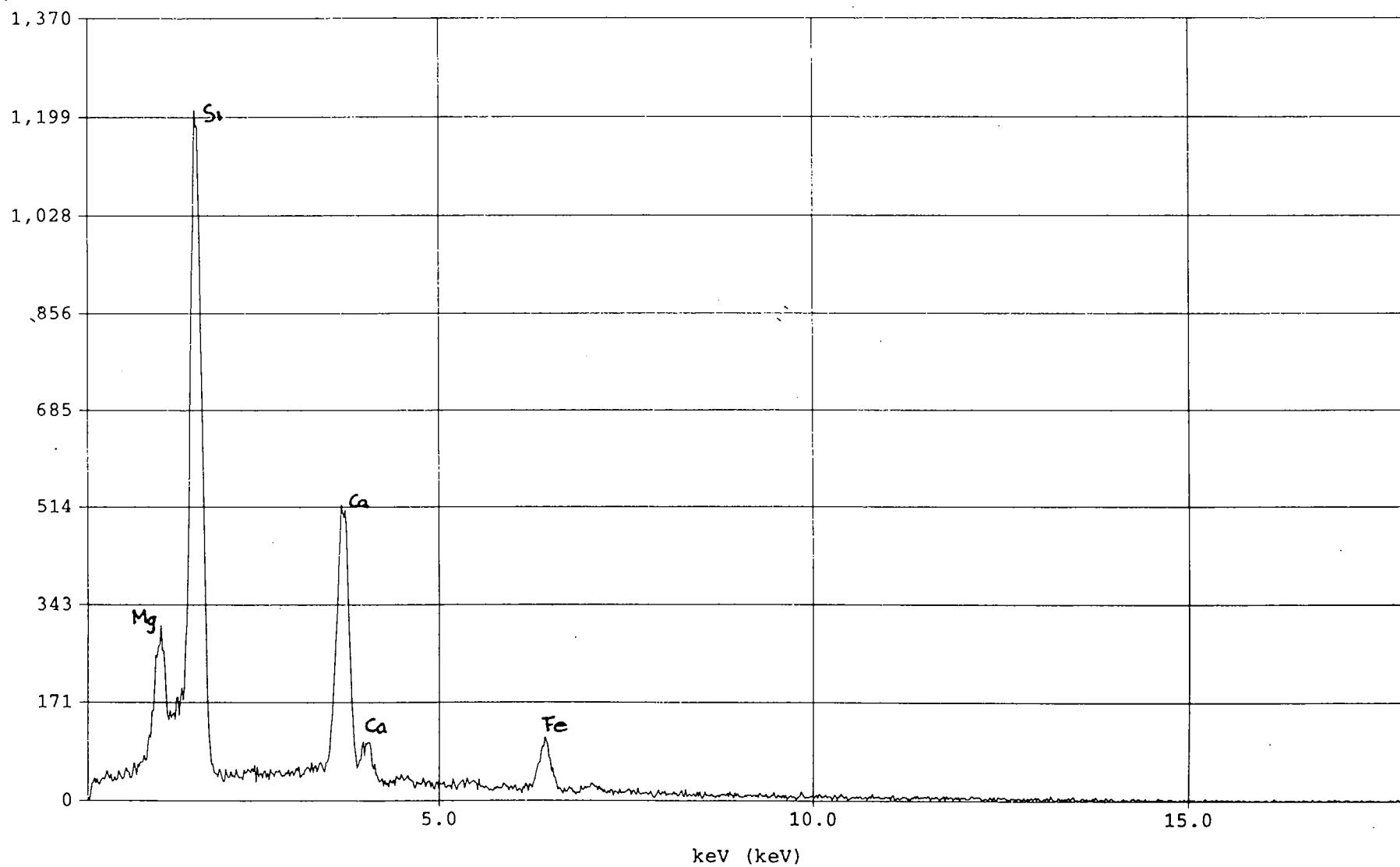
ID(1): MP 2 03 C



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Spectrum Plot Routine

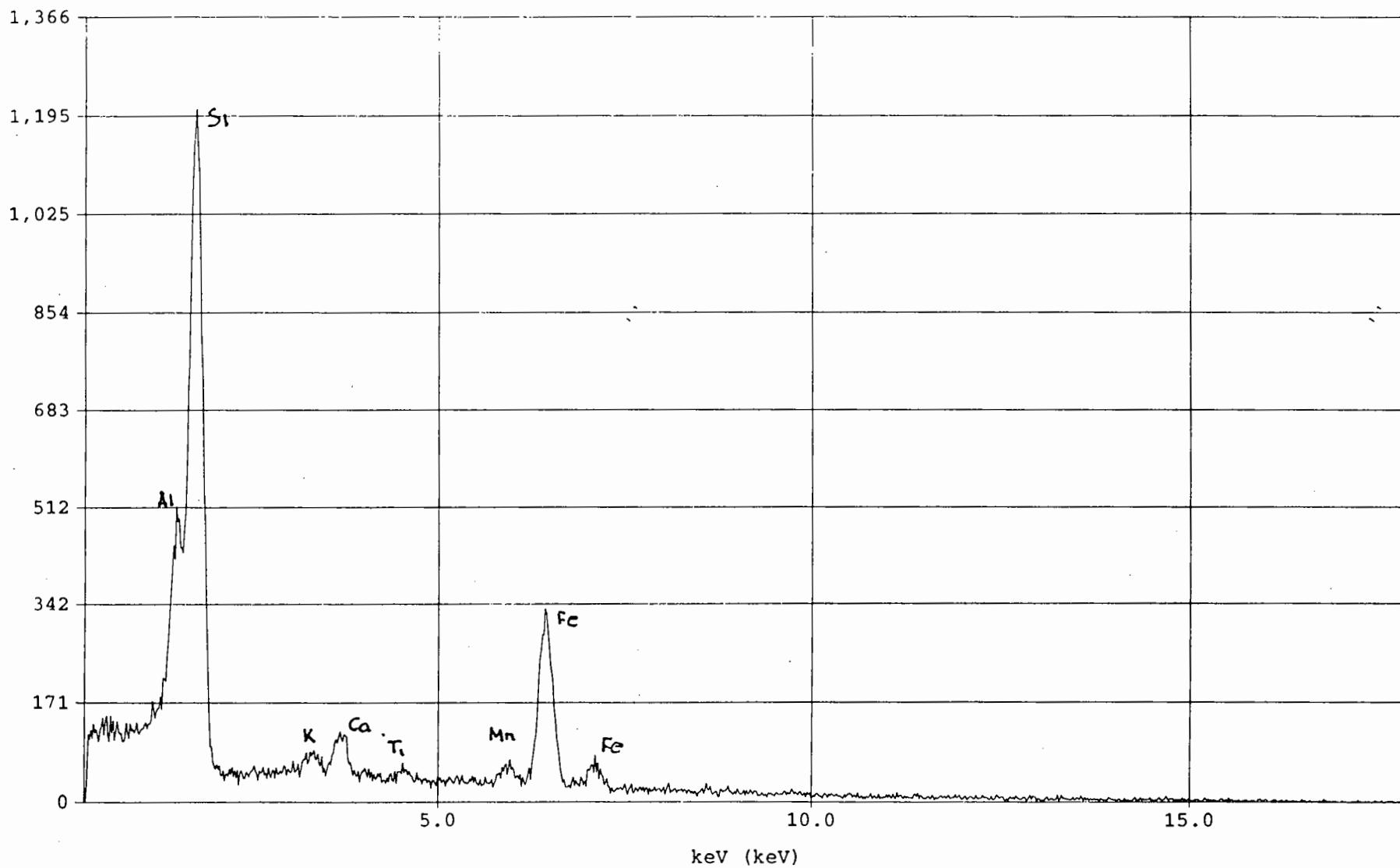
ID(1): MP 401



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Spectrum Plot Routine

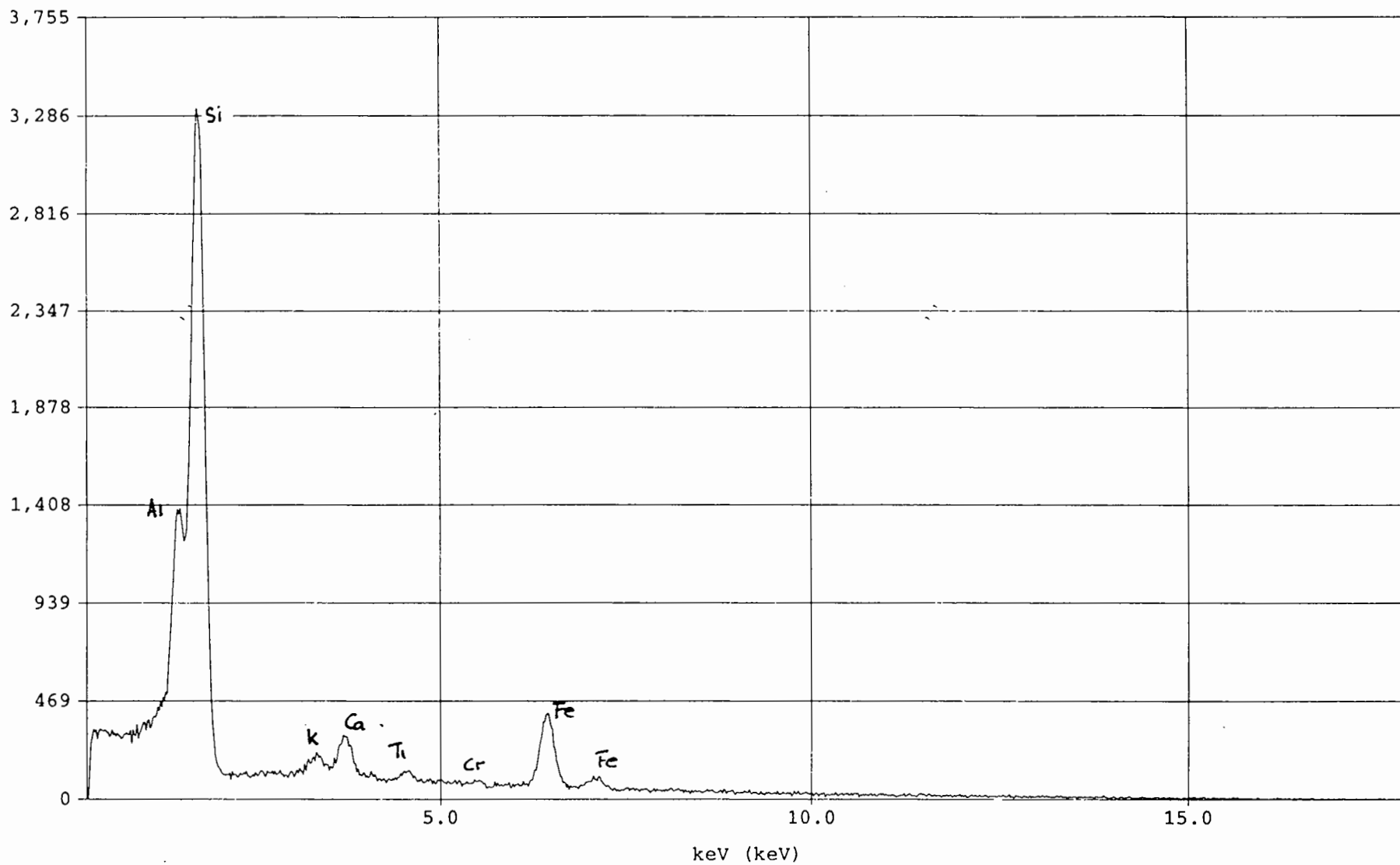
ID(1): # 57 07



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Spectrum Plot Routine

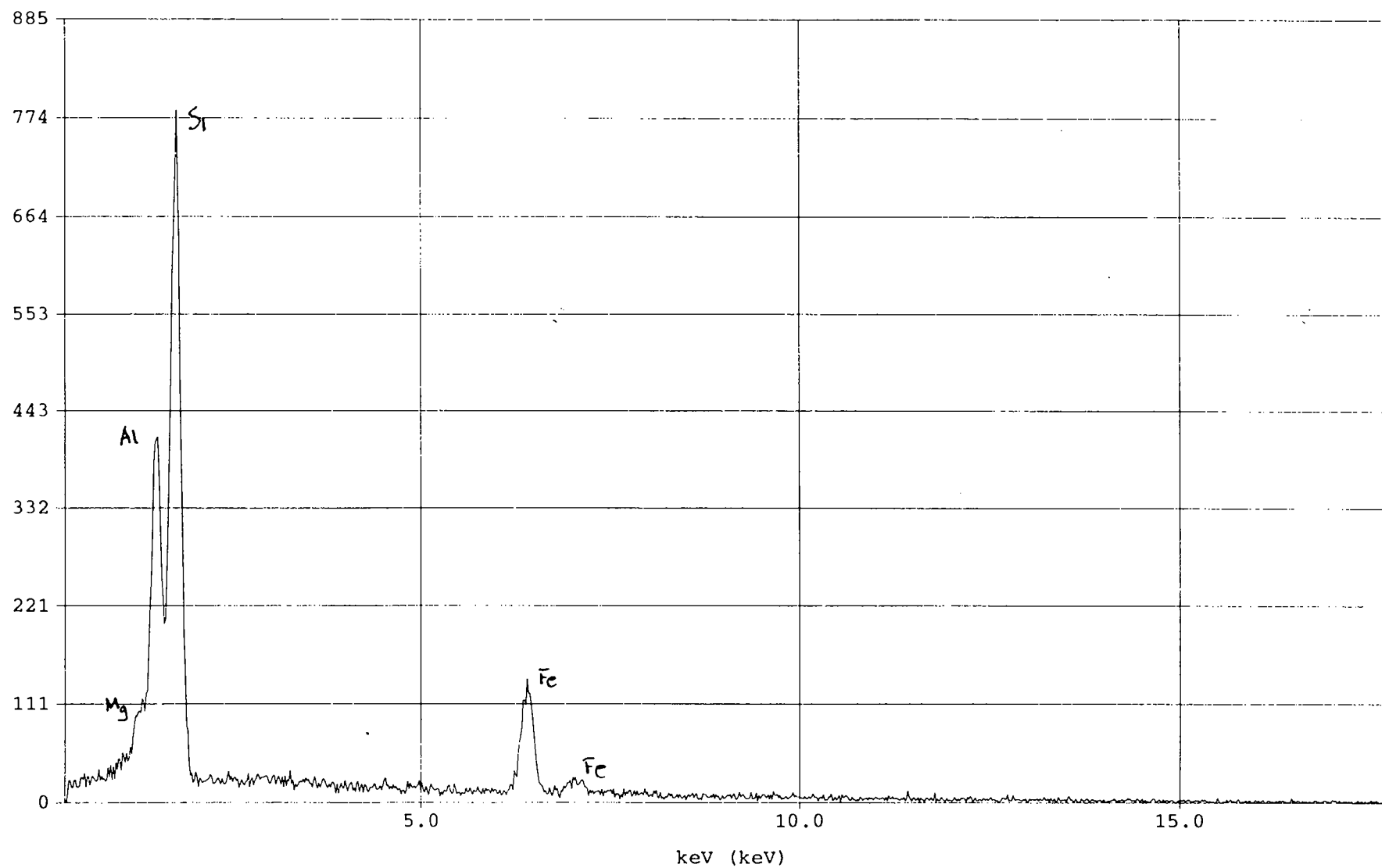
ID(1): # 57 08



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Spectrum Plot Routine

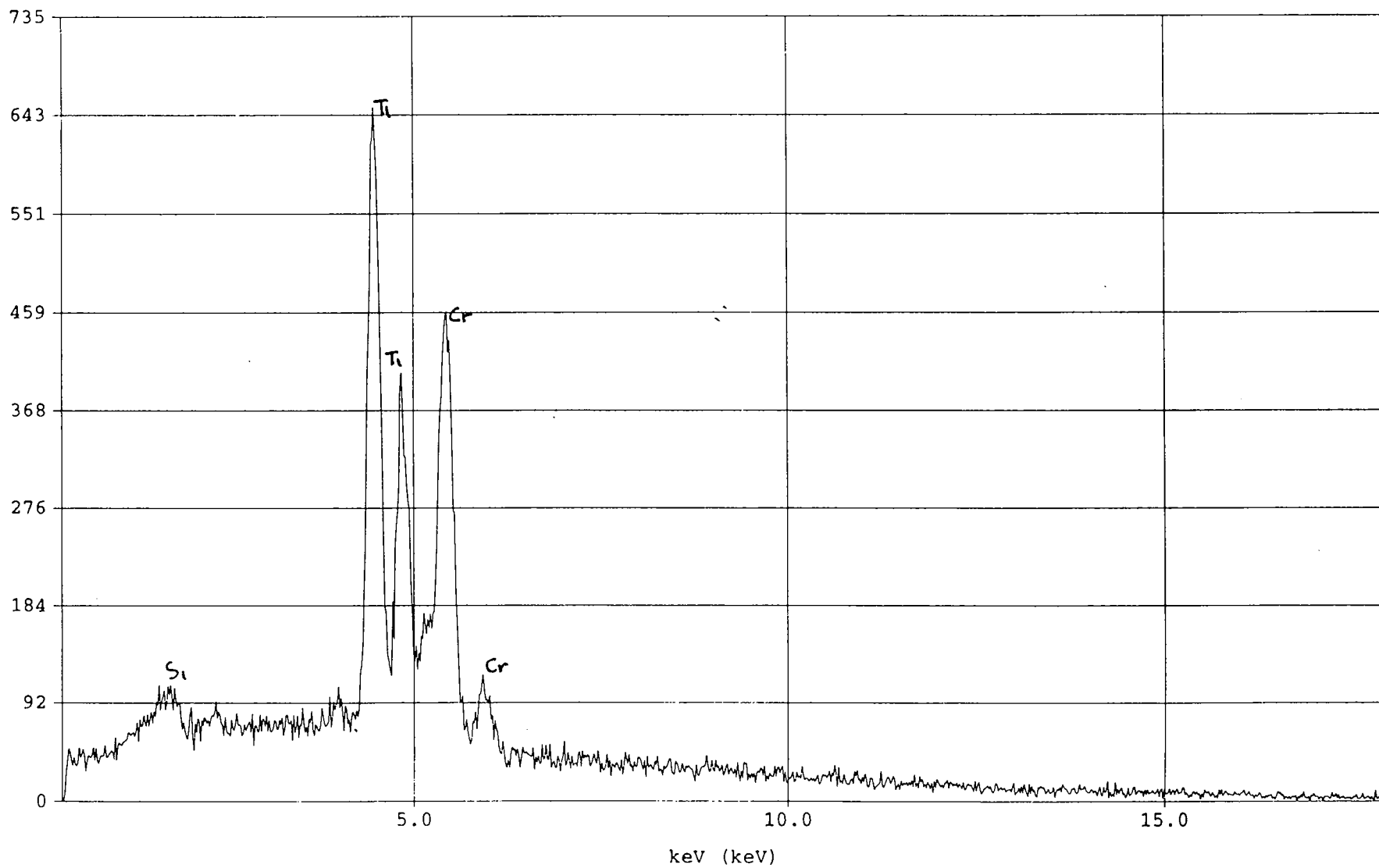
ID(1): # 64 blk



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Spectrum Plot Routine

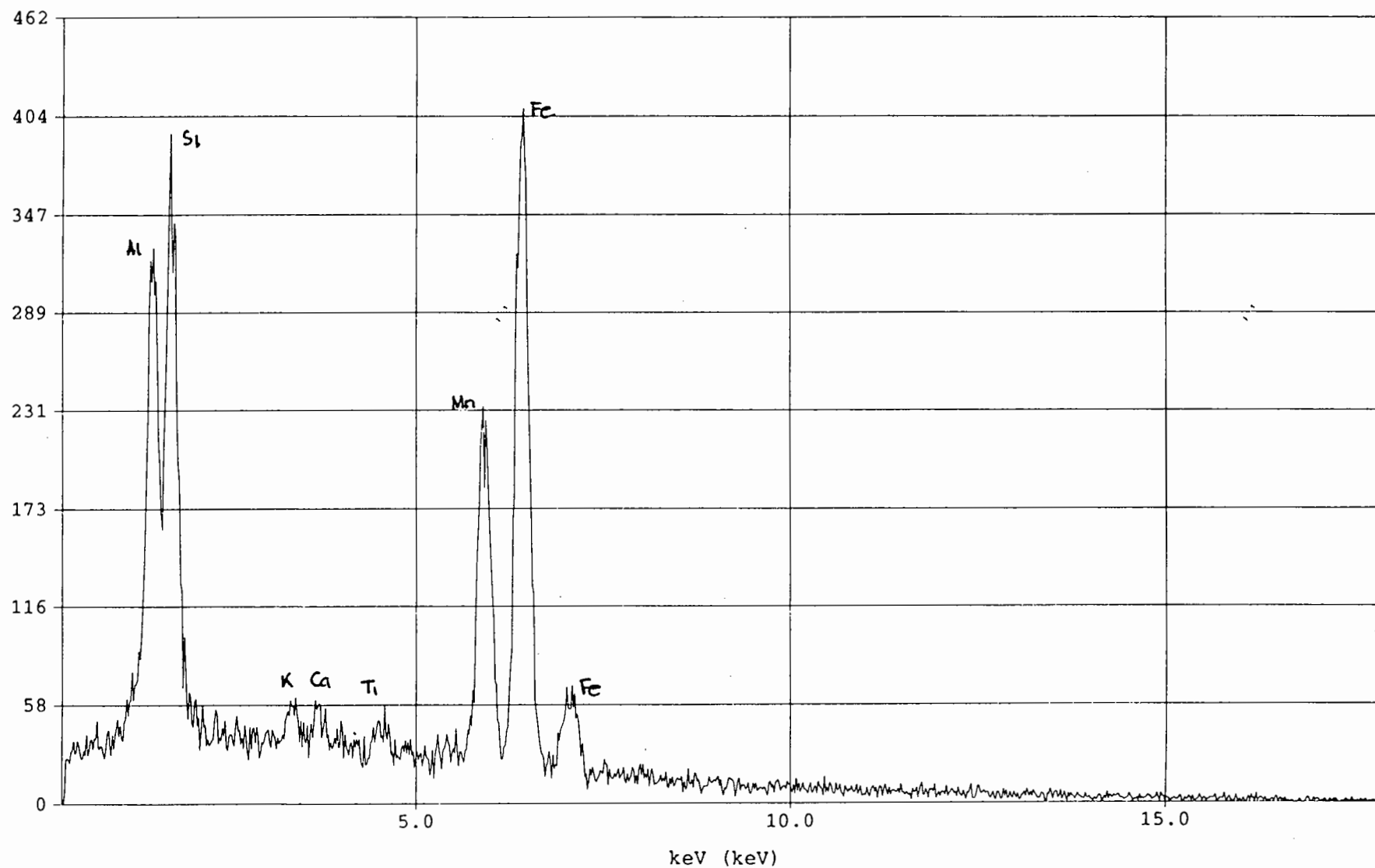
ID(1): # 64 06 BULK 01



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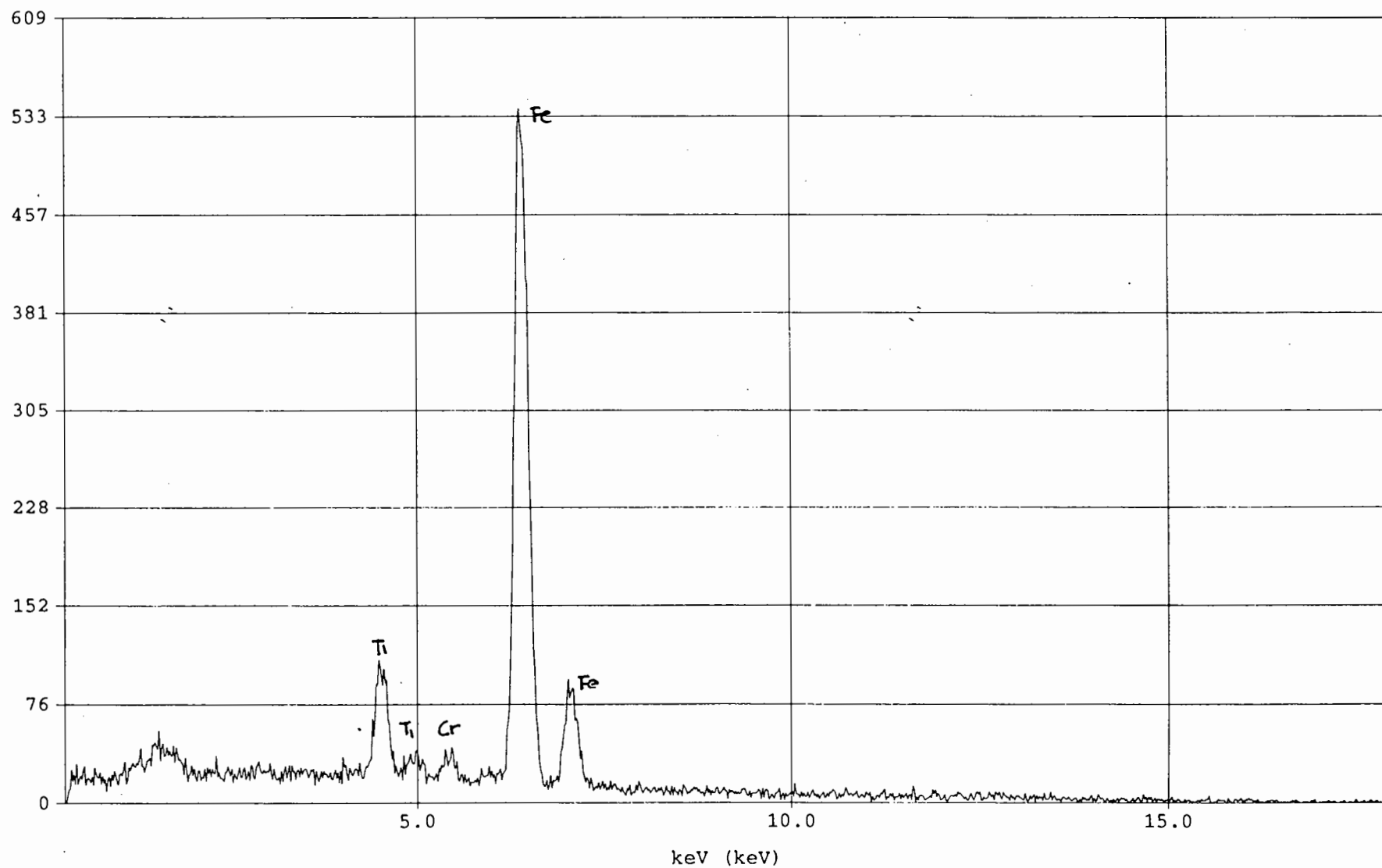
ID(1): # 64 6 BULK 02



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Spectrum Plot Routine

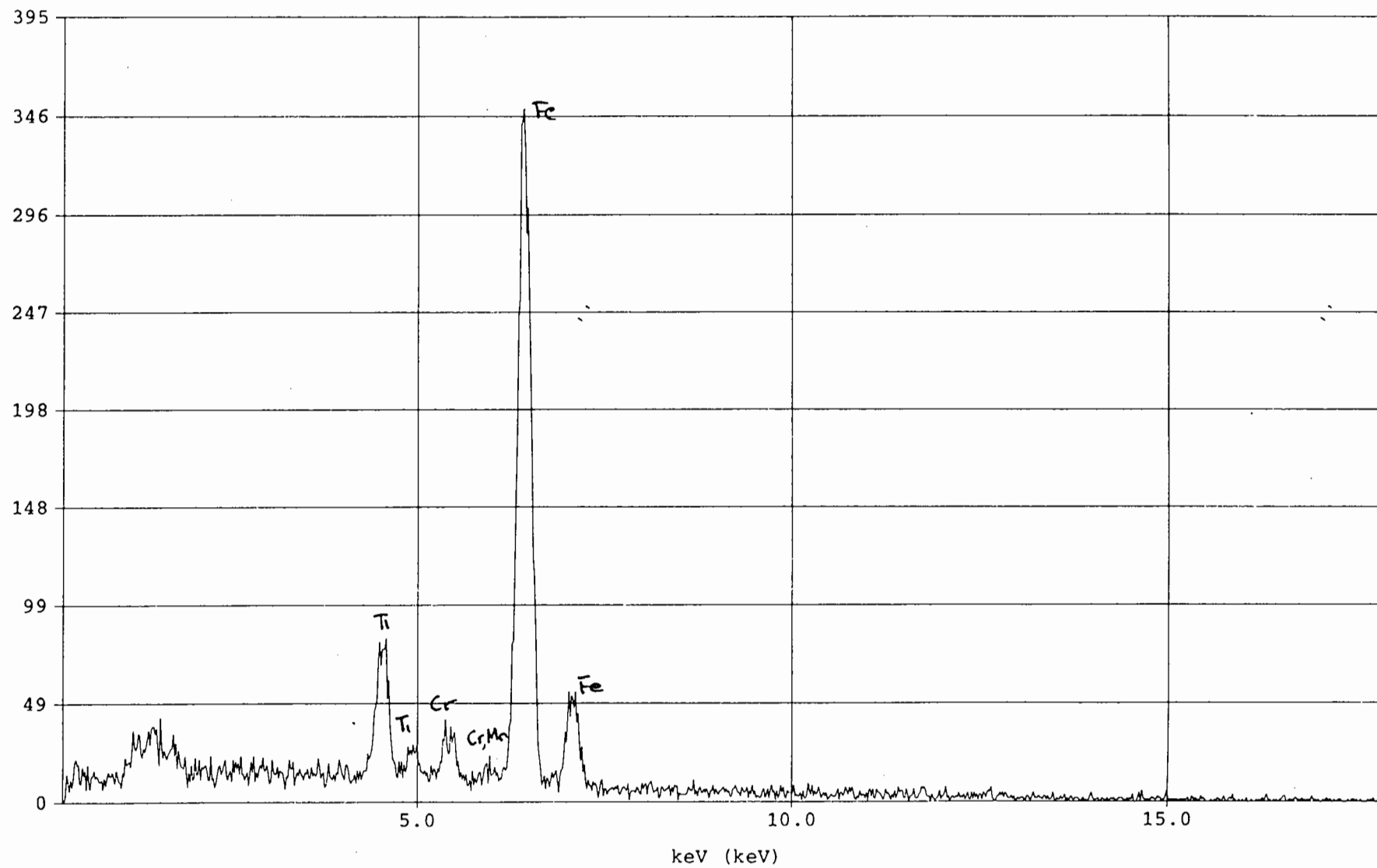
ID(1): # 64 GRAVITY CONCENTRATE 01



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Spectrum Plot Routine

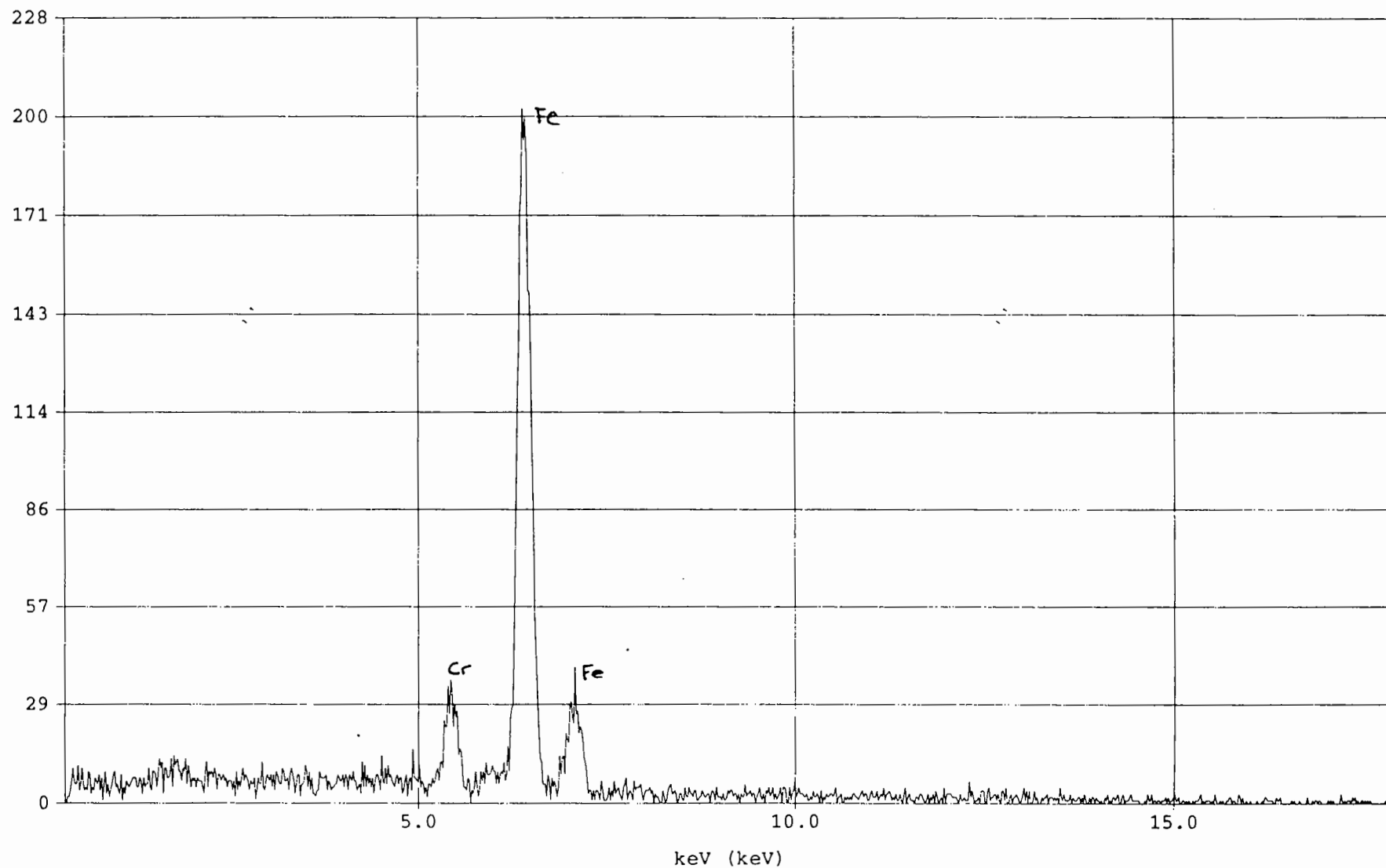
ID(1): # 64 GRAVITY CONCENTRATE 02



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Spectrum Plot Routine

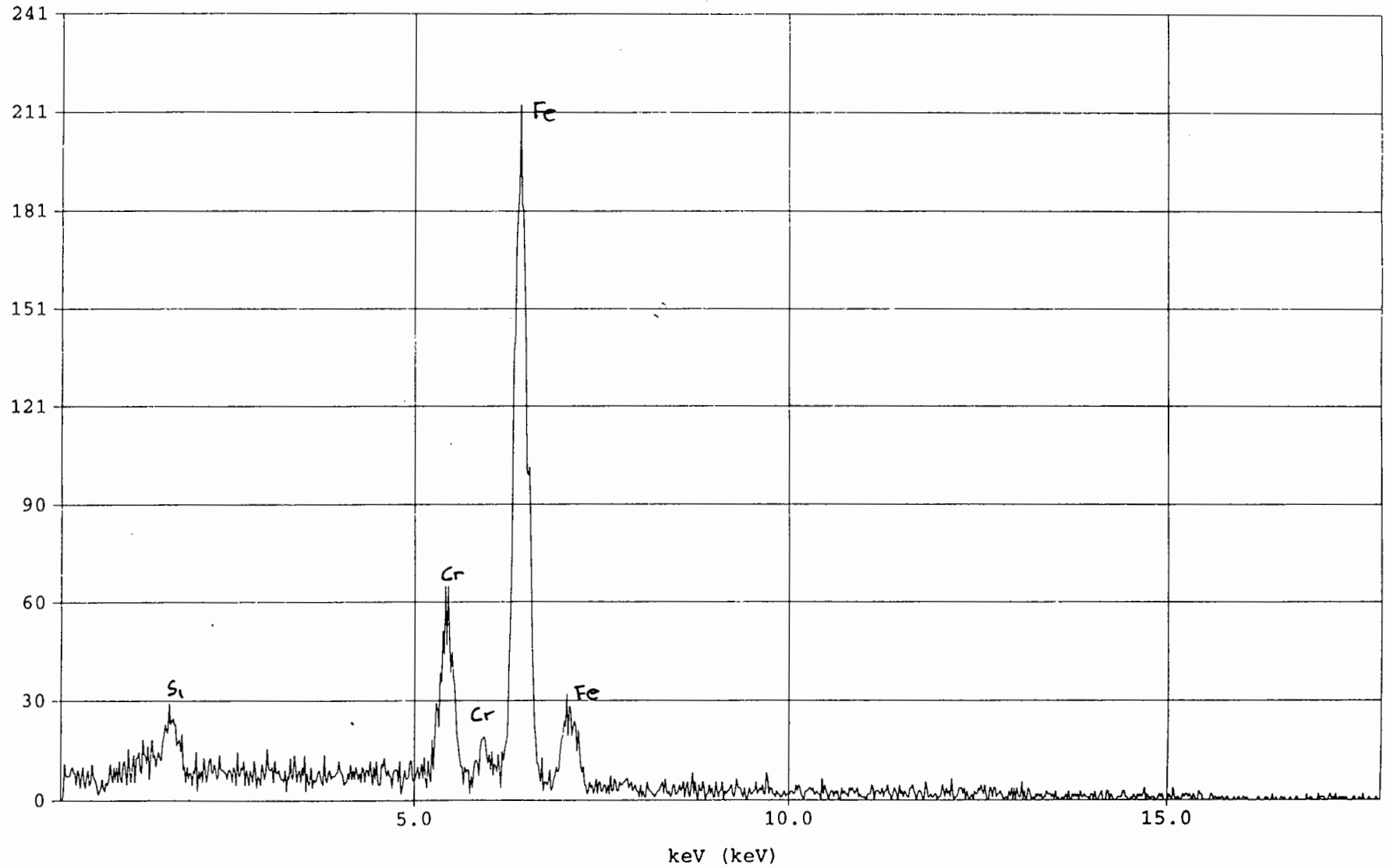
ID(1): # 64 GRAVITY CONCENTRATE 03



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Spectrum Plot Routine

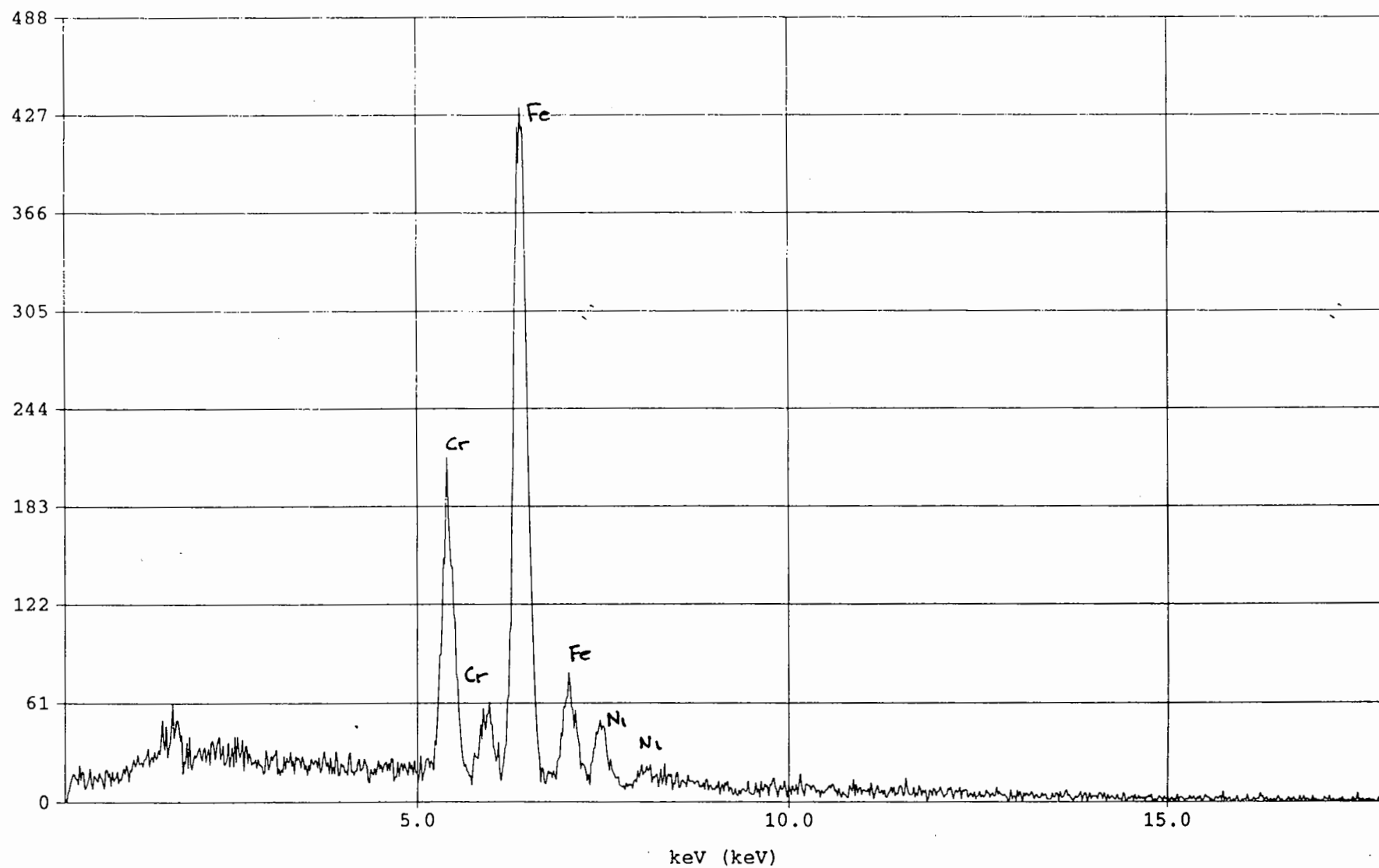
ID(1): # 64 GRAVITY CONCENTRATE 04



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Spectrum Plot Routine

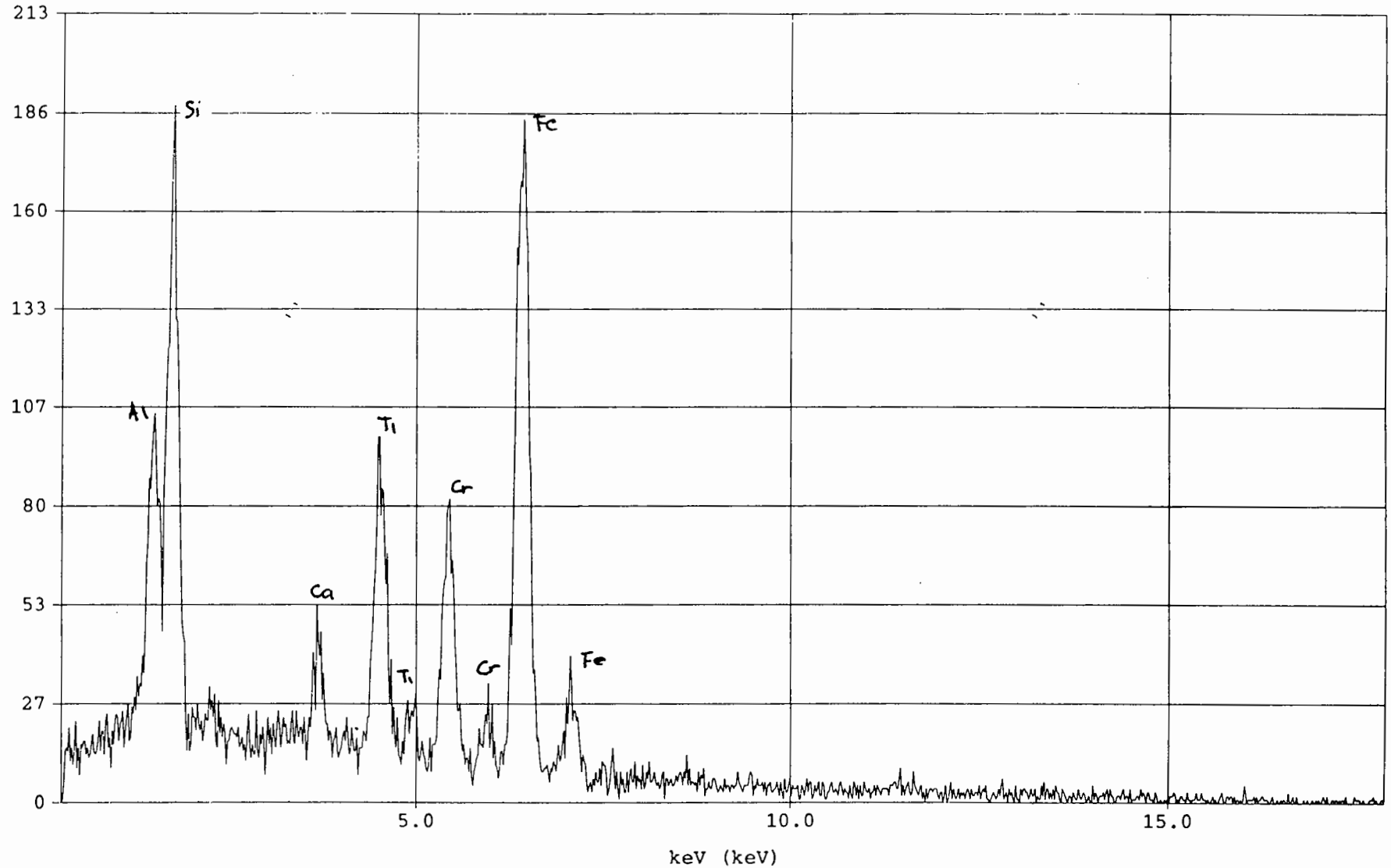
ID(1): # 65 01A



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Spectrum Plot Routine

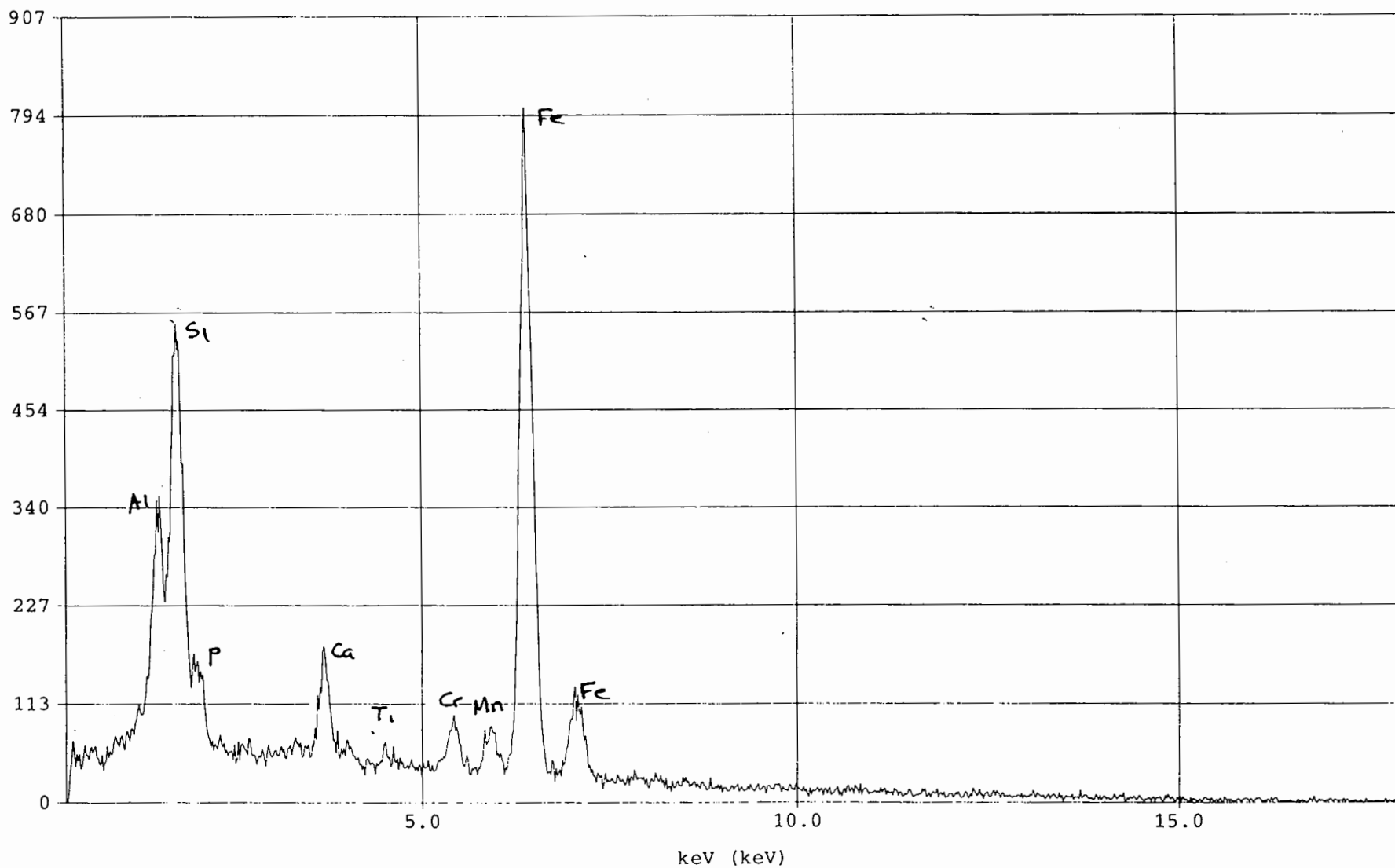
ID(1): # 72 03



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Spectrum Plot Routine

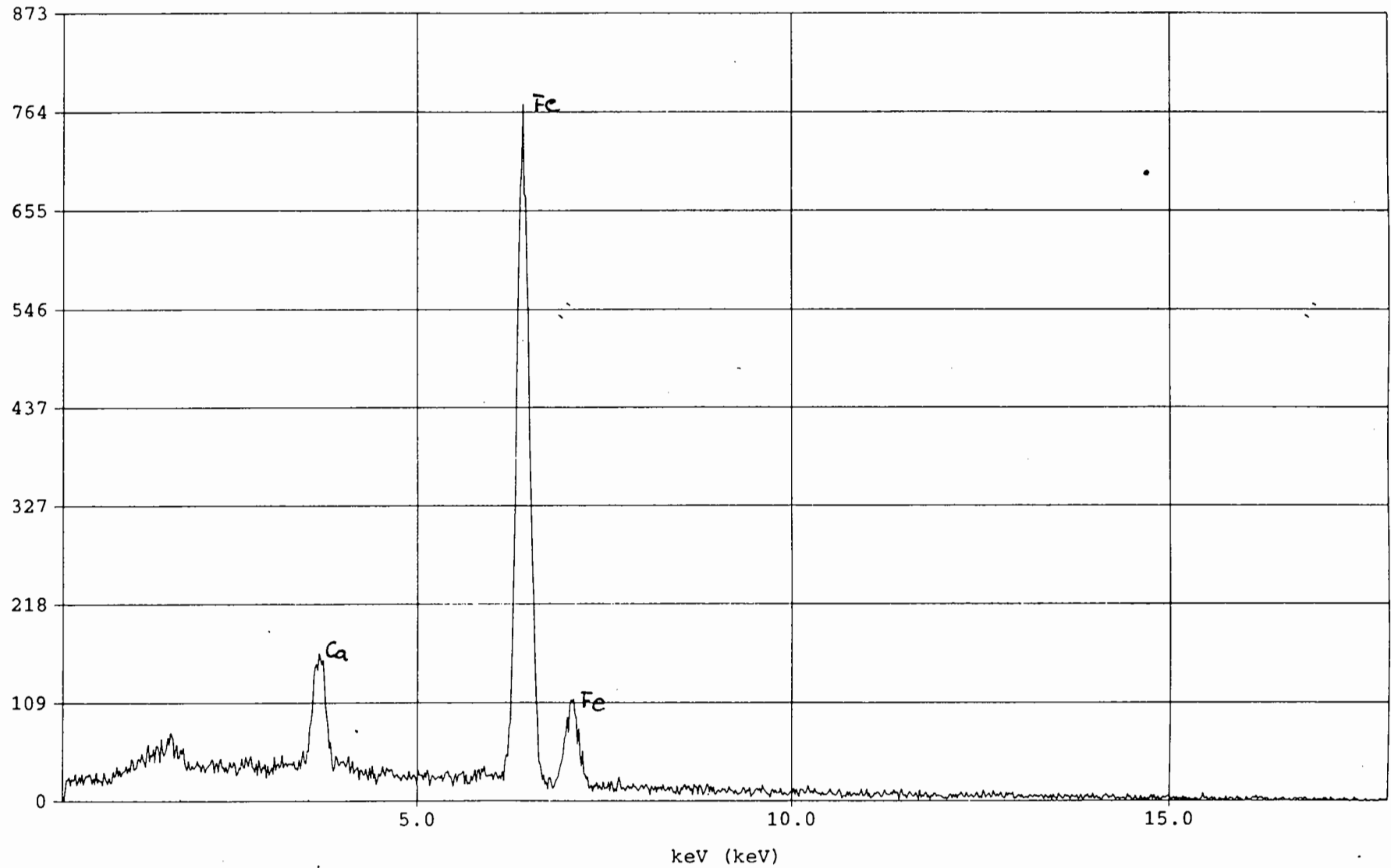
ID(1): # 72 blk 02



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Spectrum Plot Routine

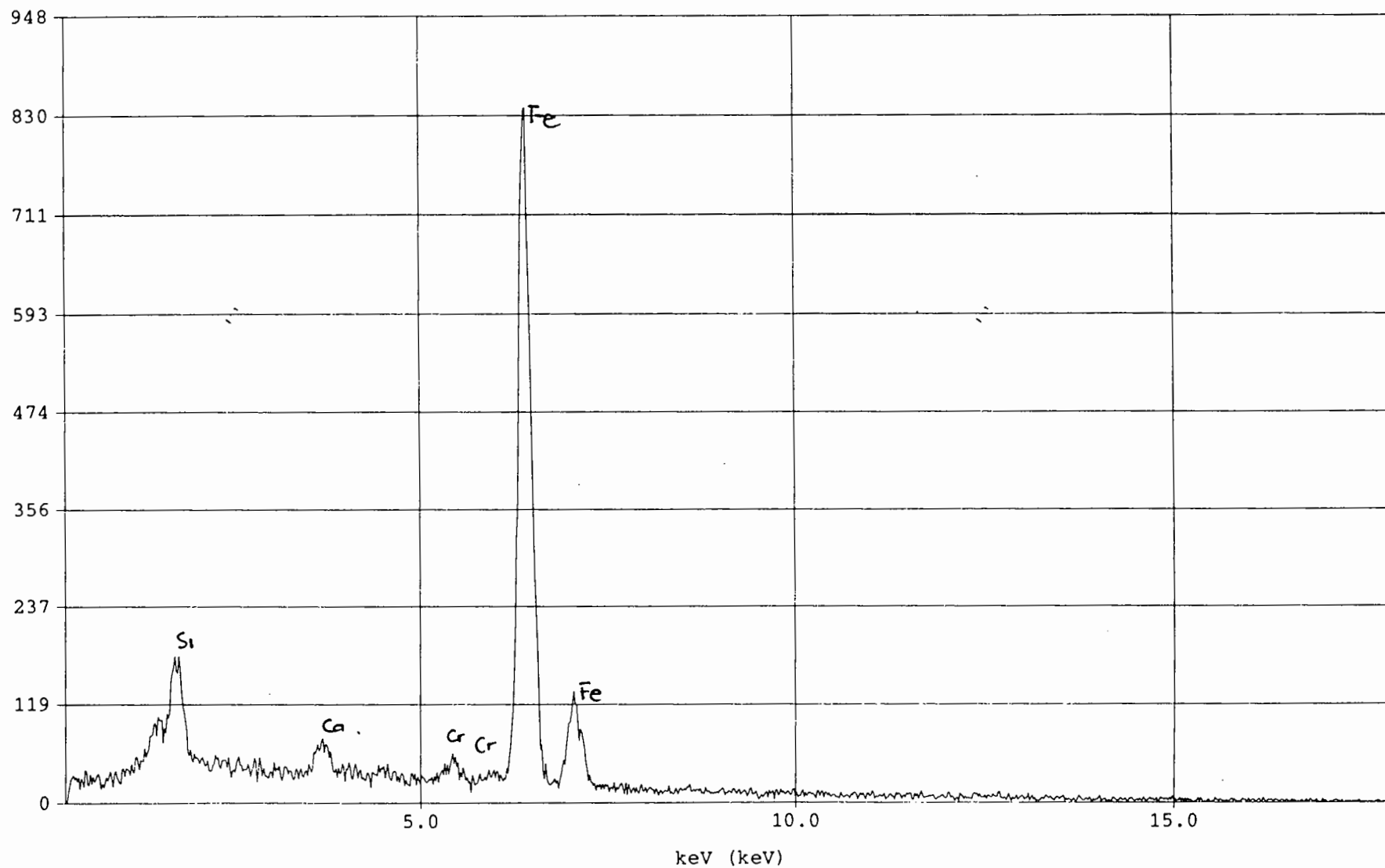
ID(1): # 72 BULK 03 A



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Spectrum Plot Routine

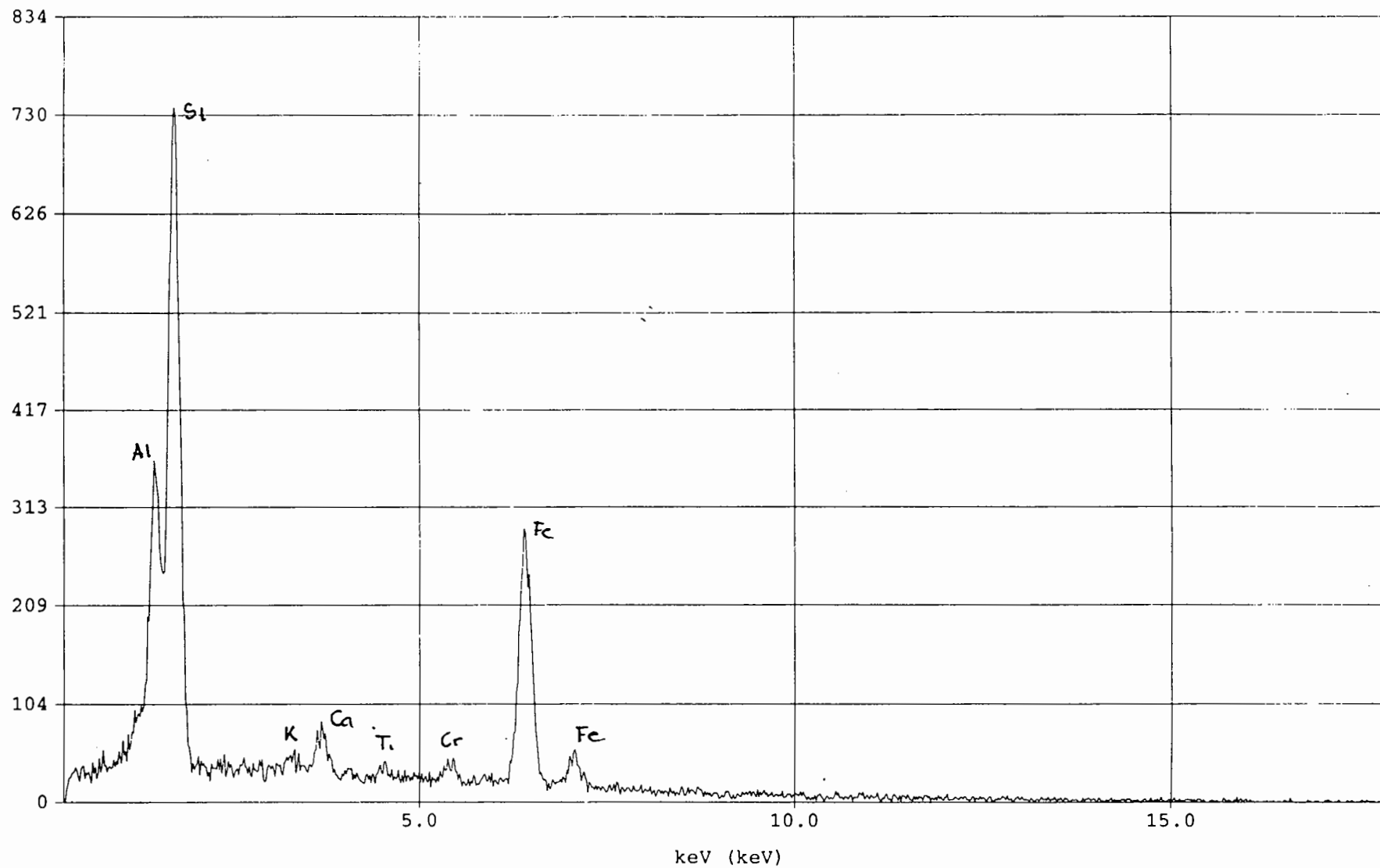
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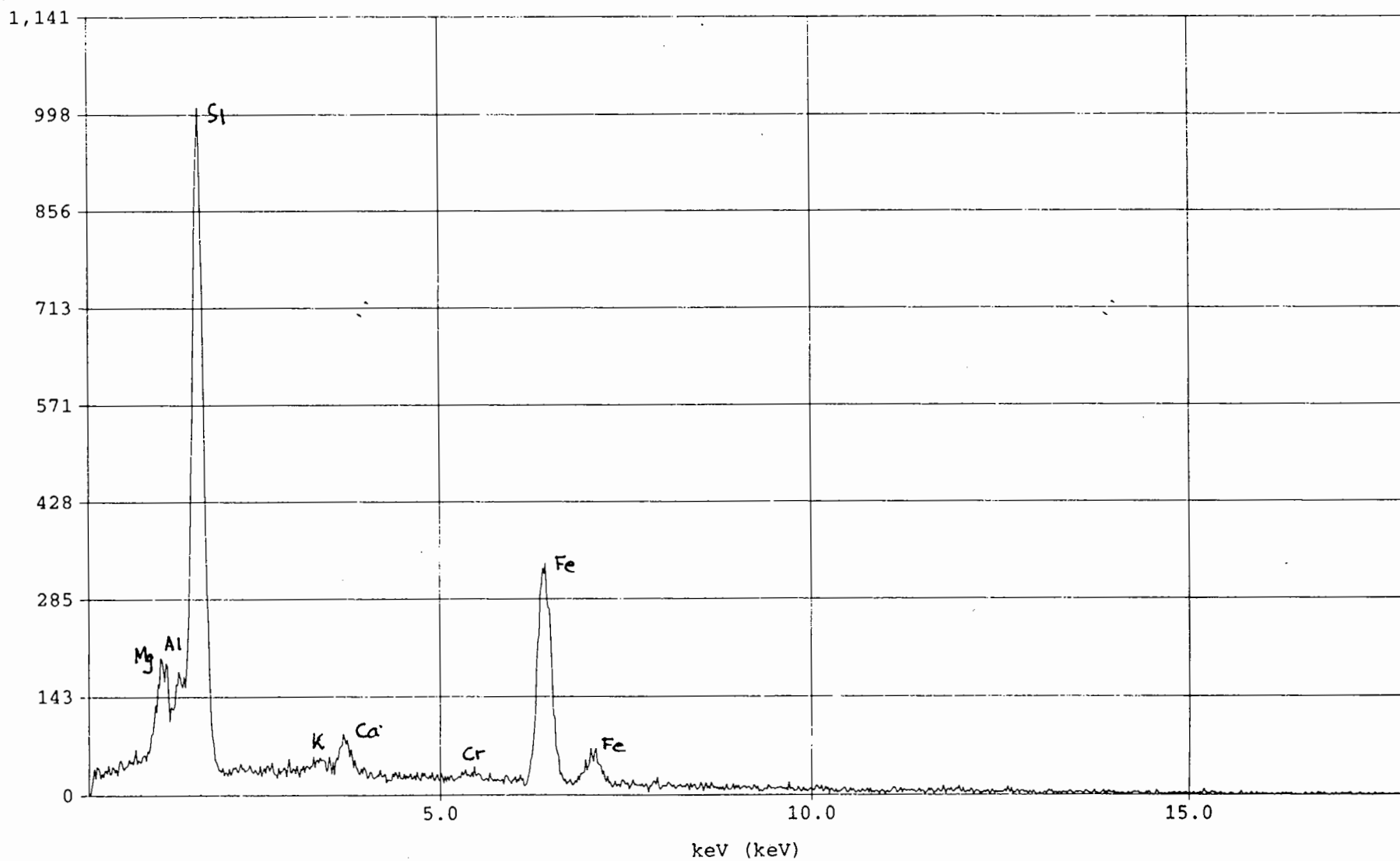
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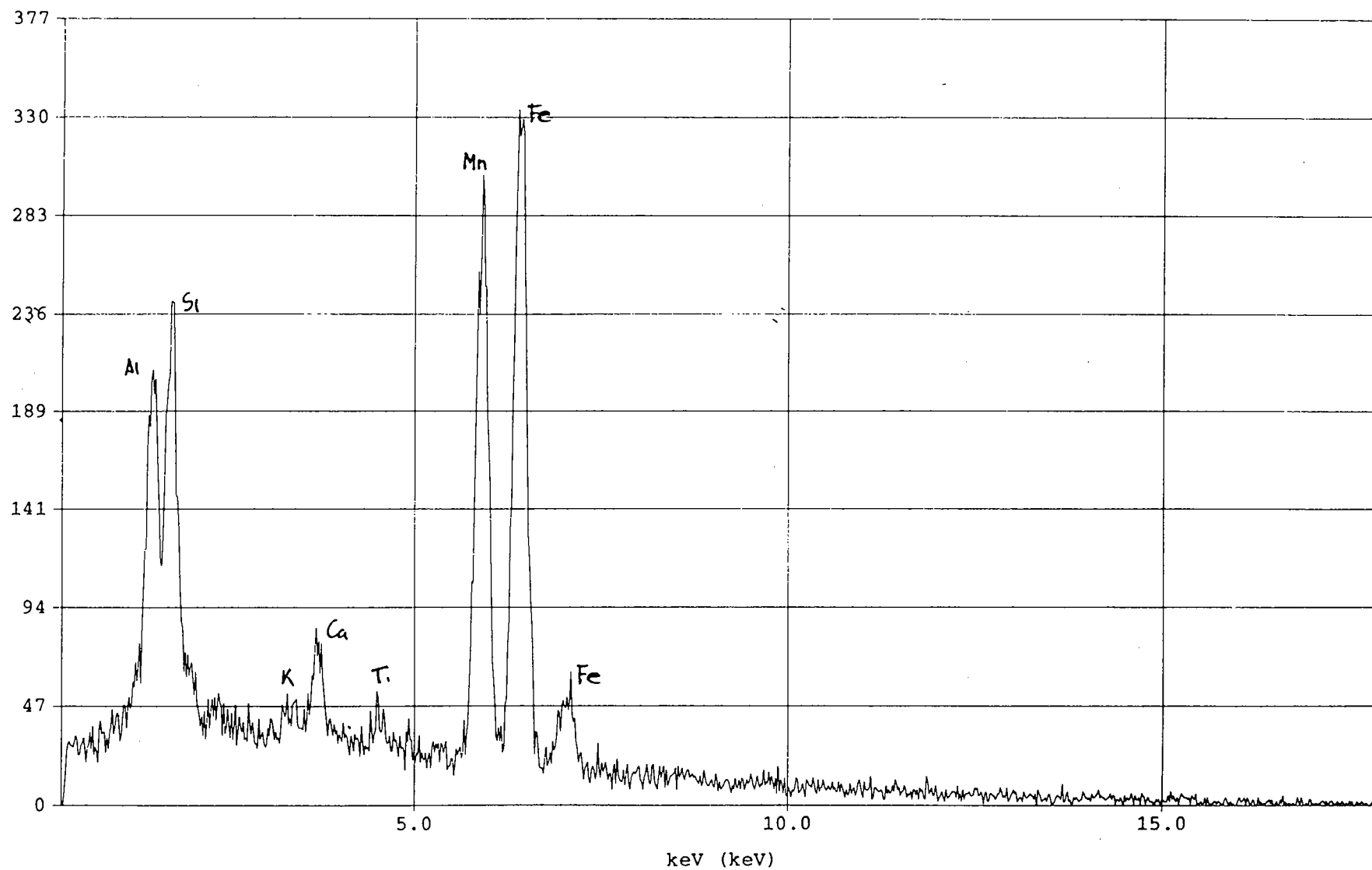
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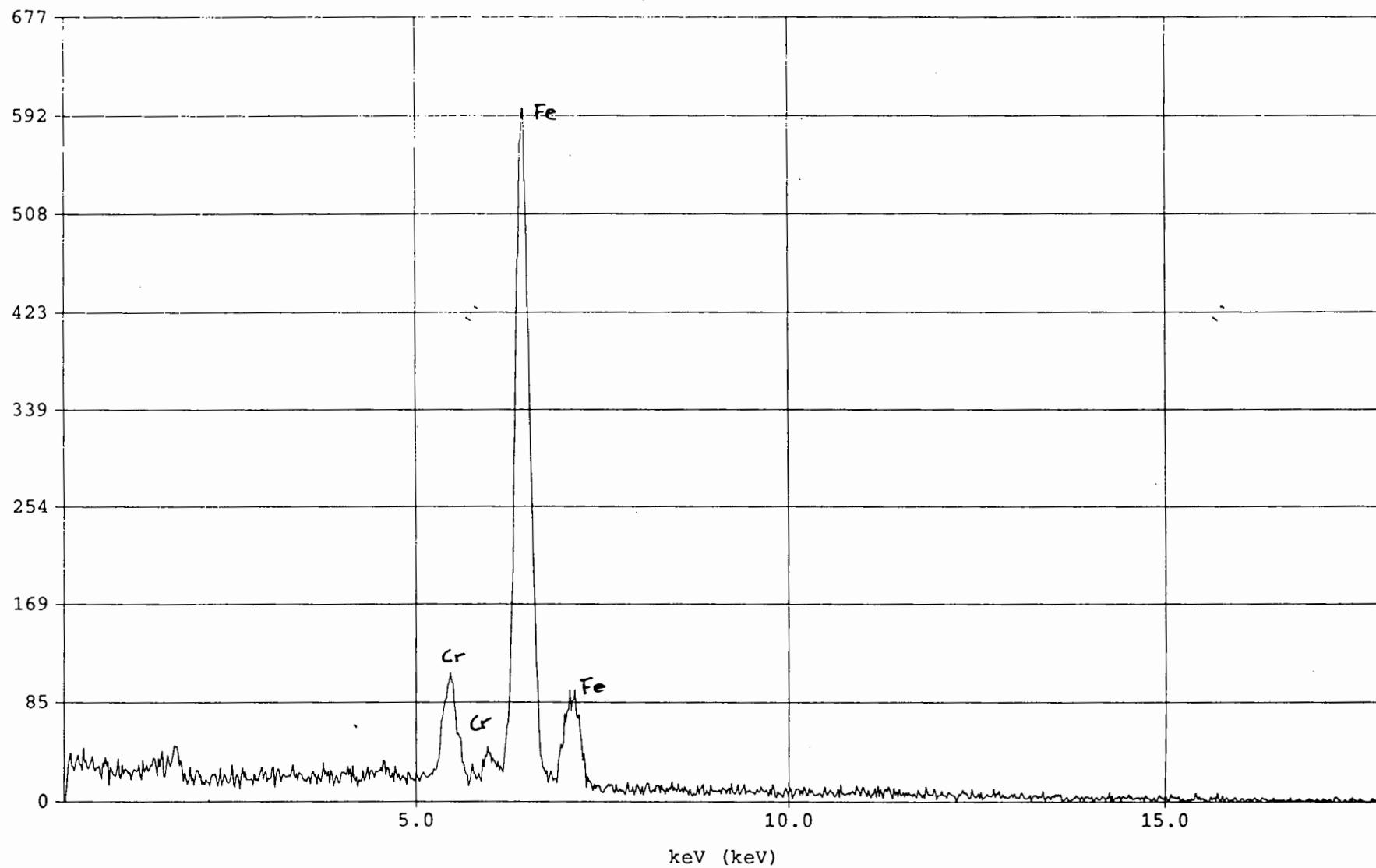
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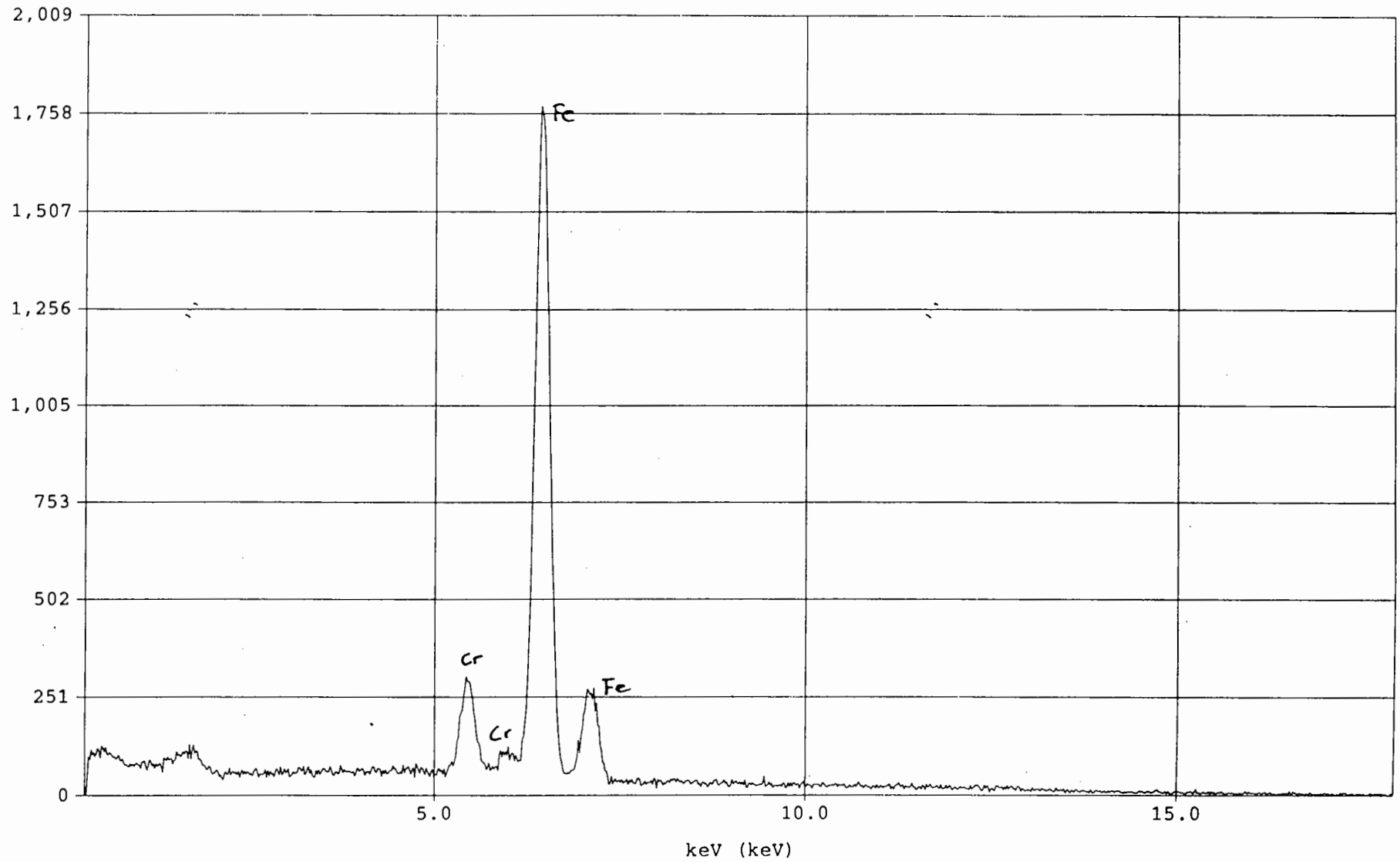
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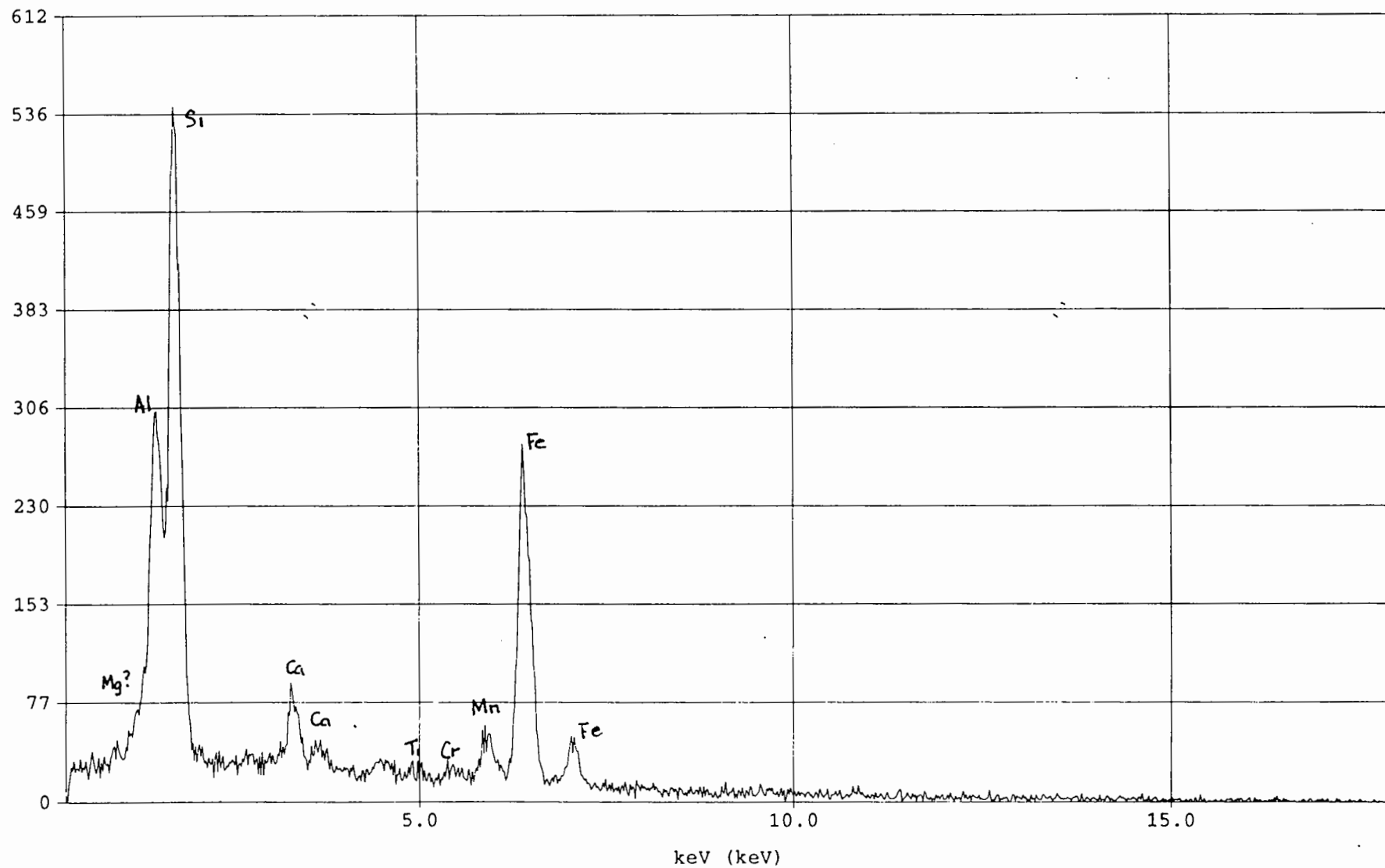
ID(1): # 72 GRAVITY CONCENTRATE 02



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ID(1): # 76 BULK 05



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<p>One factor in assessing metal mobility at the Frontier Hard Chrome industrial site is the degree of chromium reduction and secondary mineralization in a silt unit and underlying sand and gravel aquifer that extends from the site toward the Columbia River. Samples were analyzed by ICP-AES for metals concentration, scanning electron microscopy/electron microprobe for mineralogical texture and microanalysis, powder x-ray diffraction for mineral identification, and optical microscopy for textural observations. Microprobe analysis showed that chromium occurred in metallic particles originating in an uppermost Fill Unit, and in iron oxides, iron-titanium oxides and fine-grained iron aluminum silicates in the both the Silt and Aquifer Units. X-ray diffraction analysis showed that the fine-grained fraction of the Silt and Aquifer Units contained an abundant suite of detrital clay minerals including primarily illite, chlorite, and smectite, and lesser kaolinite. The presence of chlorite and smectite is consistent with the microprobe observation of iron-bearing aluminum silicates in the fine grained fraction of the samples. Chromium concentration in the fine-grained material was elevated to a level consistent with chromium in the bulk material and about 10-20 times nearby background concentrations, suggesting that an important contributor to the bulk chromium content resides in the clay minerals.</p>				
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