Response to
New York State
Department of Environmental Conservation
Request for Additional Information

Submitted to:

New York Department of
Environmental Conservation
Division of Environmental Remediation-Region 9
270 Michigan Avenue
Buffalo, NY 14203
Attn: Mr. Michael J. Hinton, P.E.

LAN
LAN ASSOCIATES INC.
ENVIRONMENTAL AND FACILITIES ENGINEERING
66 CUNA STREET ■ ST. AUGUSTINE, FL 32084-3619
904-824-6999 FAX ■ 904-824-0726

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Department of Environmental Conservation
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Submitted to:

New York Department of
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Division of Environmental Remediation-Region 9
270 Michigan Avenue
Buffalo, NY 14203
Attn: Mr. Michael J. Hinton, P.E.

Prepared by:

LAN Associates, Inc.
66 Cuna Street
St. Augustine, FL 32084
on behalf of
SKW Metals & Alloys, Inc.

July 15, 1999
LAN Ref. #2.3269.22

LAN
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66 CUNA STREET ■ ST. AUGUSTINE, FL 32084-3619
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LAN
LAN ASSOCIATES SINCE 1965
ENGINEERING • PLANNING • ARCHITECTURE • SURVEYING, INC.
66 CUNA STREET, ST. AUGUSTINE, FLORIDA 32084-3619
(904) 824-6999 • EMAIL: LAN-FL@LAN-FL.COM • FAX (904) 824-0726

July 15, 1999

VIA CERTIFIED MAIL
Article No. Z 349 337 367

Mr. Michael J. Hinton, P.E.
New York Department of Environmental Conservation
Division of Environmental Remediation--Region 9
270 Michigan Avenue
Buffalo, NY 14203

Subject: Response to DEC Request
for Additional Information
LAN Ref. #2.3269.22

Dear Mr. Hinton:

In response to your letter of April 12, 1999 (Attachment 1), LAN Associates hereby submits the following additional information.

General Information:
SKW Metals and Alloys, Inc., is currently known as CC Metals and Alloys, Inc. (CCMA). The change is in name only. The business has the same management and ownership.

Item #1 refers to the first bullet in your April 12th letter:
A definition of ferro-chromium dust was presented in the site-screening work plan, which LAN Associates submitted on behalf of CCMA. That definition stated that ferro-chromium dust contains clay-size particles and a total chromium concentration between 700 and 1,500 milligrams per kilogram (mg/kg). A letter in support of this determination from Science Applications International Corporation (SAIC) was included in the site-screening work plan. For your convenience, the SAIC letter with laboratory results is included as Attachment 2. The letter thanked SKW (CCMA), on behalf of the U.S. EPA, for helping SAIC obtain samples of ferro-chromium dust from emissions at CCMA's Niagara Falls ferroalloy production facility.

The total chromium content of the SAIC ferro-chromium dust sample is approximately 1,560 mg/kg, which represents independent third-party documentation of the chromium content in the dust. During the site-screening investigation, however, a conservative chromium concentration range of 700 to 1,500 mg/kg was used to determine if on-site materials contained ferro-chromium dust.

To LAN's knowledge, the only other source of ferro-chromium dust in the USA is the Macalloy Corporation located in Charleston, SC. Total metal analyses of dust samples collected at the Macalloy facility was conducted by General Engineering Laboratories on August 17, 1992 (Attachment 3, page 6). The results show that the chromium content of the ferro-chromium fume dust is 4,450 mg/kg, which is well above the level obtained by SAIC at the CCMA facility. However, the site-screening concentration used for determining the presence of ferro-chromium dust at the CCMA facility was a total chromium of 700 mg/kg or greater. This concentration is well below the available third-party, total chromium concentrations for ferro-chromium dust.

A complete study of the particle-size distribution of fume dust generated from the CCMA furnace operation (Attachment 4) was completed in 1992 by Dr. Wojciech Z. Misiolek, a materials engineering consultant and professor at Rensselaer Polytechnic Institute, Troy, New York. Dr. Misiolek's investigation revealed that the average particle size of the fume dust ranged from 0.39 to 0.55 microns and that 70 to 88 percent of the particles were less than 5 microns. Clay-sized particles are defined by the American Society of Testing and Materials (ASTM) as occurring between 1 and 5 microns.

Additional particle-size distribution and cumulative particulate emission rates for ferro-chromium fume dust are provided in the section on "Ferroalloy Production" of a manual on the *Metallurgical Industry* (1995), compiled by the U.S. EPA (Attachment 5). These results show that 91 percent of the ferro-chromium fume dust is less than 10 microns in particle size and 88 percent is less than 6 microns in particle size.

Item #2 refers to the second bullet in your April 12th letter:

The range of particle size for ferro-chromium fume dust is discussed above. Formation of crystalline or amorphous fume dust is dependent on the rate of cooling (temperature drop) during condensation (the phase change from vapor to liquid) and solidification (the phase change from liquid to solid). The formation of crystal structure (the regularly repeated arrangement of atoms, ions, or molecules into identifiable geometric shapes and patterns) requires a slow cooling process with sufficient time for crystals to form and grow. If the cooling process occurs rapidly, the crystallization process will be incomplete or not occur. The result of rapid cooling is a glassy structure that is amorphous (without a crystal structure or form).

At the CCMA facility, fume dust is generated during the ferroalloy melting process, which occurs in a submerged electric arc furnace where temperatures range from 2000°C to over 3000°C. Fume (vaporized dust) emissions from the furnace are conveyed into ventilated ductwork. The ventilation rapidly cools the fume vapor into liquid and then into a solid (particulate dust). This process occurs so rapidly that the fume vapor and liquid do not have sufficient time to form a crystalline solid. Instead, the fume vapor is rapidly cooled and forms a solid without crystal form. Therefore, the cooled fume dust is classified as a non-crystalline (amorphous) solid.

X-ray diffraction is an analytic method that examines the lattice pattern of the crystal structure (Attachment 6, page 64). This method is typically used to identify minerals but can also distinguish between amorphous and crystalline materials. Crystalline material will generate a distinct pattern of diffraction peaks, whereas amorphous material will not produce diffraction peaks. An example of crystallization is given in Attachment 6, page 71, which discusses the formation of amorphous and crystalline volcanic rocks, where formation is also dependent on the cooling rate of the volcanic melt material. Another example of the formation of an amorphous solid is glass-making (Attachment 7), a process that converts silica sand into glass by melting the sand and cooling it rapidly into an amorphous solid.

Item #3 refers to the third bullet in your April 12th letter:

As stated in the revised site-screening work plan, the purpose of the investigation was to determine if ferro-chromium dust was present at CCMA's Witmer Road property. Therefore, a definition of ferro-chromium dust was presented in the work plan along with a screening method for identifying it. The interpretation section of the work plan states that laboratory analysis of samples collected at the Witmer Road property would be compared with the known total chromium concentration of ferro-chromium dust samples. That concentration was reported to range between 700 and 1,200 mg/kg total chromium. As defined in the work plan, the purpose of the site-screening investigation was not to determine if elevated concentrations of chromium were present, but to determine if ferro-chromium dust was present in areas outside of the closed landfill cells on the Witmer Road property.

Item #4 refers to the fourth bullet in your April 12th letter:

Section 2.3, page 9, paragraph 2, the last sentence of the site screening report will be revised. The revision will state, "*In LAN Associates' opinion, these results indicate that parameters of concern in the stormwater discharge from the CCMA property are not a significant threat to human health or the environment.*"

Item #5 refers to the fifth bullet in your April 12th letter:

During the construction phase of the Interim Remedial Measures (IRM), grade stakes were used to determine the required cut-and-fill elevations for site grading. A site plan showing the location of all grade stakes is included as Attachment 8. Grade stake number 477 is located near the southeast portion of the property. The grade stake provided a convenient reference point to the baghouse bags, which were located nearby.

Item #6 refers to the sixth bullet in your April 12th letter:
The cover page of the site-screening report will be resubmitted with the signature and seal of a New York State registered professional engineer.

If the information that is provided in this letter meets with your approval, we will be glad to resubmit it as an addendum or as inserts to a Revised Site-Screening Report. If you have any questions regarding this letter, please do not hesitate to contact me.

Very truly yours,

Harry H. Hutton, P.G.
Senior Hydrogeologist

HHH:jw
2-3269.22-L-DEC Request-990715-hhh

Attachments: #1–DEC Letter of April 8, 1999
#2–SAIC Letter with Lab Results.
#3–General Engineering Lab Results
#4–Particle-Size Distribution Study
#5–"Ferroalloy Production" (*Metallurgical Industry*), EPA AP-42 Manual (10/86)
#6–"Rocks and Minerals" Chapter 3: *Earth* (NY: W.H. Freeman, 1982)
#7–"Is Glass a Polymer?" (Univ. of So. Miss., Dept. of Polymer Science, 1997)
#8–Site Plan: Grade Stake Layout 5

Copies to: Mr. Ed Bredniak, CCMA

ATTACHMENTS

Attachment 1

NYSDEC Letter of April 8, 1999

23269.22

New York State Department of Environmental Conservation
Division of Environmental Remediation, Region 9
270 Michigan Avenue, Buffalo, New York, 14203-2999
Phone: (716) 851-7220 FAX: (716) 851-7226

John P. Cahill
Commissioner

APR 12 1999

5/1/99

April 8, 1999

Mr. Edward S. Bredniak
SKW Metals and Alloys, Inc.
PO Box 217
Calvert City, Kentucky 42029

Dear Mr. Bredniak:

Vanadium Corporation of America
Site #932001
SKW Operable Unit 1
Site Screening Report

The New York State Departments of Environmental Conservation (NYSDEC) and Health (NYS DOH) have reviewed the Site Screening Report prepared by LAN Associates, dated February 17, 1999. We have prepared the following comments that need to be addressed before the report can be accepted by the agencies.

- Section 1.0 Introduction - Supporting information documenting the physical and chemical properties of ferrochromium and ferrochromium-silica dust must be provided. Basically, we need third party information, such as industry reports that document the expected chromium concentrations and physical characteristics,
- Section 2.2 Phase I Results and Discussions, page 7 - Again, independent supporting documentation is needed for the particle size and amorphous vs. crystalline discussions. Also, the location of the SKW baghouse dust collector, when the baghouse samples were collected and how the process that generated the dust is different or similar to the former process at he SKW facility that generated the dust found on the Witmer Road site,
- Section 2.3 Phase I Interpretation, page 8 - What is the basis for comparing the total chromium to 700 mg/kg? The expected background for New York State as reported in TAGM 4046 is 40 mg/kg. Therefore concentrations of total chromium over 40 mg/kg can be considered "elevated",

- Section 2.3 Phase I Interpretation, page 9 - The NYSDEC and the NYS DOH are responsible for determining if the storm water discharged is or is not a threat to public health or the environment,
- Section 3.1 Baghouse Dust Removal, page 10 - Reference is made to stake #477 for the location of the baghouse bags that were found during the IRM project. You must explain what stake #477 is and include the site made that shows the grade stake location or eliminate the reference to stake #477, and
- This document must be signed by a New York State Registered Professional Engineer.

Please make the necessary revisions and provide the corrected pages for inclusion into the Site Screening Report. If you have any questions, please call me at (716) 851-7220.

Sincerely,

Michael J. Hinton

Michael J. Hinton, P.E.
Environmental Engineer II
Division of Environmental Remediation
Region 9

MJH:lej

cc: Mr. Daniel King, NYSDEC, Division of Environmental Remediation, Region 9
Ms. Maura Desmond, NYSDEC, Div. of Environmental Enforcement, Buffalo
Ms. Karen Mauirano, NYSDEC, Div. of Environmental Remediation, Albany
Ms. Dawn Hettrick, NYS DOH, Albany
Mr. Guy D. Van Doren, LAN Associates

(a:sitesc1.wpd)

2

Attachment 2

SAIC Letter with Lab Results

SAIC
Science Applications International Corporation
An Employee-Owned Company

January 11, 1991

Mr. Russ G. Trivedi
SKW Alloys, Inc.
P.O. Box 368
Niagara Falls, NY 14392-0368

RE: Results of Analysis of Ferrochromium-silicon Baghouse Dust Samples

Dear Mr. Trivedi:

I would like to thank you on behalf of EPA for providing us with valuable information concerning the generation and treatment of ferrochromium-silicon emission control dust. We sincerely appreciate your willingness to take time out of your busy schedule to help us obtain samples of the emission control dust. Our efforts to establish reasonable treatment methods and achievable standards for the waste are enhanced by your support.

For your information, I have enclosed a copy of the analytical results generated from the samples provided at your facility. If you have any question regarding these analyses or questions on the project, please feel free to call me at (703) 734-3136 or Ron Turner of EPA RREL at (513) 569-7775.

Sincerely,

Henry Huppert
Chemical Engineer

enclosure

cc: Ron Turner, EPA RREL
Ed McNicholas, SAIC
Tom Wagner, SAIC
Mark Colangelo, SAIC

8400 Westpark Drive, McLean, Virginia 22102
Other SAIC Offices: Albuquerque, Boston, Colorado Springs, Dayton, Huntsville, Las Vegas, Los Angeles, Oak Ridge, Orlando, Palo Alto, San Diego, Seattle, and Tucson

Versar INC

Data Qualifier Flags

J	For Target Compounds: This flag is used when mass spectral data indicates the presence of a compound but the result is less than the specified detection limit but still greater than zero. For Non Target Compounds: This flag indicates that the concentration is an estimated value, assuming a 1 to 1 response with the internal standard.
B	This flag is used when the analyte is found in the blank as well as in the sample. It indicates possible/probable contamination and warns the data user to take appropriate action.
U	This flag states that the compound was analyzed for but was not detected. The number is the minimum attainable detection limit for the sample.
X or T	This flag states that the mass spectrum does not meet EPA CLP criteria for confirmation, but compound presence is strongly suspected.
E	This flag is used to indicate that the quantitation of the analyte is outside the linear calibration of the curve and that dilution was required in order to properly quantitate.
D	This flag is used to indicate the value for the target analyte was calculated from a dilution (see "E" flag above).
Y	This flag is used when a matrix spike compound is also confirmed present in the unspiked sample.

Flags excerpted from and established by the
US EPA Contract Lab Program (CLP) protocol.

Metals

1

ORGANIC ANALYSES DATA SHE

FIELD SAMPLE NO.

SKW-01

Client : VERSAR_DIV. _24______ Site: SAIC_MIN. _PROC.

Lab Name: VERSAR_INC. Control No.: 3312____ Code: SAICBDAT Batch: 11______

Matrix : SOIL____________ Lab Sample ID: 28867______

Level (low/med): _________ Date Received: 08/16/90_

Concentration Units (ug/L or mg/kg wet weight): MG/KG

CAS No.	Analyte	Concentration	C	Q	M
7429-90-5	Aluminum	12100			P
7440-36-0	Antimony	1.2	U		P
7440-38-2	Arsenic	100	U	E	P
7440-39-3	Barium	138			P
7440-41-7	Beryllium	0.52			P
7440-43-9	Cadmium	0.29	U		P
7440-70-2	Calcium	7420			P
7440-47-3	Chromium	1560			P
7440-48-4	Cobalt	1.0			P
7440-50-8	Copper	3.5			P
7439-89-6	Iron	1270			P
7439-92-1	Lead	273			P
7439-95-4	Magnesium	121000			P
7439-96-5	Manganese	1510			P
7439-97-6	Mercury	0.098	U		CV
7440-02-0	Nickel	16.1			P
7440-09-7	Potassium	2720			P
7782-49-2	Selenium	5.5			P
7440-22-4	Silver	0.29	U		P
7440-23-5	Sodium	778			P
7440-28-0	Thallium	23.9			P
7440-62-2	Vanadium	1.5			P
7440-66-6	Zinc	3270			P
	Molybdenum	0.29	U		P
	Lithium	1.3			P
	Strontium	107			P
	Tin	240	U		A
	ChromiumVI	121			A

Color Before: GREY_____ Clarity Before: ______ Texture: FINE__

Color After : YELLOW___ Clarity After: CLEAR_ Artifacts: ______

Comments:

__________"E" - SEVERE MATRIX INTERFERENCE________________________________

ORGANIC ANALYSES DATA SHE

FIELD SAMPLE NO.

SKW-FB

Client : VERSAR_DIV._24______ Site: SAIC_MIN._PROC.

Lab Name: VERSAR_INC. Control No.: 3312____ Code: SAICBDAT Batch: 11_____

Matrix : SOIL___________ Lab Sample ID: 28868____

Level (low/med): ________ Date Received: 08/16/90_

Concentration Units (ug/L or mg/kg wet weight): MG/KG

CAS No.	Analyte	Concentration	C	Q	M
7429-90-5	Aluminum	6.8			P
7440-36-0	Antimony	1.3	U		P
7440-38-2	Arsenic	1.1	U		P
7440-39-3	Barium	0.43			P
7440-41-7	Beryllium	0.10	U		P
7440-43-9	Cadmium	0.30	U		P
7440-70-2	Calcium	0.70	U		P
7440-47-3	Chromium	0.25			P
7440-48-4	Cobalt	0.30	U		P
7440-50-8	Copper	0.46			P
7439-89-6	Iron	1.2			P
7439-92-1	Lead	2.3	U		P
7439-95-4	Magnesium	1.0			P
7439-96-5	Manganese	0.23			P
7439-97-6	Mercury				NR
7440-02-0	Nickel	0.74			P
7440-09-7	Potassium	37.6	U		P
7782-49-2	Selenium	2.4	U		P
7440-22-4	Silver	0.30	U		P
7440-23-5	Sodium	5.2			P
7440-28-0	Thallium	9.7			P
7440-62-2	Vanadium	0.20	U		P
7440-66-6	Zinc	0.59			P
	Molybdenum	0.30	U		P
	Lithium	0.20	U		P
	Strontium	0.10	U		P
	Tin	250	U		A
	ChromiumVI	1.0	U		A

Color Before: COLORLESS Clarity Before: CLEAR_ Texture: ______

Color After : COLORLESS Clarity After: CLEAR_ Artifacts: ______

omments:

FIELD_BLANK_HANDLED_AS_A_SOLID

3

BLANKS

Client : VERSAR_DIV._24______

Site: SAIC_MIN._PROC._____

Lab Name: VERSAR_INC. Control No.: 3312____ Code: SAICBDAT Batch: 11_____

Preparation Blank Matrix: SOIL______________

Preparation Blank Concentration Units (ug/L or mg/kg): MG/KG

Analyte	Initial Calib. Blank (ug/L)	C	Continuing Calibration Blank (ug/L) 1	C	2	C	3	C	Preparation Blank	C	M
Aluminum											
Antimony											NR
Arsenic											NR
Barium											NR
Beryllium											NR
Cadmium											NR
Calcium											NR
Chromium											NR
Cobalt											NR
Copper											NR
Iron											NR
Lead											NR
Magnesium											NR
Manganese											NR
Mercury											NR
Nickel											NR
Potassium											NR
Selenium											NR
Silver											NR
Sodium											NR
Thallium											NR
Vanadium											NR
Zinc											NR
Molybdenum											NR
Lithium											NR
Strontium											NR
Tin											NR
ChromiumVI											NR
									0.100	U	A

3
BLANKS

Client : VERSAR_DIV._24______ Site: SAIC_MIN._PROC._____

Lab Name: VERSAR_INC. Control No.: 3312____ Code: SAICBDAT Batch: 11_____

Preparation Blank Matrix: SOIL______________

Preparation Blank Concentration Units (ug/L or mg/kg): MG/KG

Analyte	Initial Calib. Blank (ug/L)	C	Continuing Calibration Blank (ug/L) 1	C	2	C	3	C	Preparation Blank	C	M
Aluminum									5.807		P
Antimony									1.396		P
Arsenic									1.100	U	P
Barium									0.100	U	P
Beryllium									0.100	U	P
Cadmium									0.300	U	P
Calcium									1.124		P
Chromium									0.540		P
Cobalt									0.300	U	P
Copper									0.300	U	P
Iron									1.931		P
Lead									2.339		P
Magnesium									0.679		P
Manganese									0.200	U	P
Mercury									0.100	U	CV
Nickel									0.955		P
Potassium									37.600	U	P
Selenium									2.400	U	P
Silver									0.300	U	P
Sodium									6.697		P
Thallium									5.700	U	P
Vanadium									0.200	U	P
Zinc									0.413		P
Molybdenum									0.300	U	P
Lithium									0.200	U	P
Strontium									0.100	U	P
Tin									250.000	U	A
ChromiumVI									0.100	U	A

3
BLANKS

Client : VERSAR_DIV._24______

Site: SAIC_MIN._PROC. ______

Lab Name: VERSAR_INC. Control No.: 3312____ Code: SAICBDAT Batch: 11_____

Preparation Blank Matrix: HOH_______________

Preparation Blank Concentration Units (ug/L or mg/kg): UG/L_

Analyte	Initial Calib. Blank (ug/L)	C	Continuing Calibration Blank (ug/L) 1	C	2	C	3	C	Preparation Blank	C	M
Aluminum	11.0	U	14.7		11.0	U	20.0		28.7		P
Antimony	13.0	U	13.0	U	13.0	U	13.0	U	64.7		P
Arsenic	11.0	U	11.0	U	11.0	U	11.0		11.0	U	P
Barium	1.0	U	1.0	U	1.0	U	1.0	U	1.0	U	P
Beryllium	1.0	U	1.0	U	1.0	U	1.0	U	1.0	U	P
Cadmium	3.0	U	3.0	U	3.0	U	3.0	U	3.0	U	P
Calcium	7.0	U	7.0	U	7.0	U	7.0	U	7.0	U	P
Chromium	2.0	U	2.0	U	2.0	U	2.0	U	2.3		P
Cobalt	3.0	U	3.0	U	3.0	U	3.0	U	3.0	U	P
Copper	3.0	U	4.0		3.0	U	3.9		12.9		P
Iron	4.0	U	4.0	U	36.2		9.7		29.6		P
Lead	23.0	U	23.0	U	23.0	U	23.0	U	23.0	U	P
Magnesium	1.0	U	1.0	U	22.5		1.8		3.8		P
Manganese	2.0	U	2.0	U	2.0	U	2.0	U	2.8		P
Mercury	0.2	U	0.2	U	0.2	U	0.2	U	0.2	U	CV
Nickel	5.0	U	6.3		5.0	U	6.4		5.0	U	P
Potassium	376.0	U	376.0	U	376.0	U	341.2		376.0	U	P
Selenium	24.0	U	24.0	U	24.0	U	24.0	U	24.0	U	P
Silver	3.0	U	3.0	U	3.0	U	3.0	U	3.0	U	P
Sodium	14.0	U	14.0	U	14.0	U	14.0	U	70.7		P
Thallium	57.0	U	57.0	U	57.0	U	57.0	U	57.0	U	P
Vanadium	2.0	U	2.0	U	2.0	U	2.0	U	2.0	U	P
Zinc	2.0	U	2.0	U	2.0	U	2.0	U	11.8		P
Molybdenum	3.0	U	3.0	U	3.0	U	3.0	U	3.0	U	P
Lithium	2.0	U	2.0	U	2.0	U	2.0	U	7.2		P
Strontium	1.0	U	1.0	U	1.0	U	1.0	U	1.0		P
Tin	2500.0	U	2500.0	U	2500.0	U			2500.0	U	A
ChromiumVI	10.0	U	10.0	U	10.0	U					A

5A
SPIKE SAMPLE RECOVERY

FIELD SAMPLE NO.

SKW-01 S

Client : VERSAR_DIV._24 Site: SAIC_MIN._PROC.

Lab Name: VERSAR_INC. Control No.: 3312 Code: SAICBDAT Batch: 11

Matrix : SOIL

Level (low/med):

Concentration Units (ug/L or mg/kg wet weight): MG/KG

Analyte	Control Limit %R	Spiked Sample Result (SSR)	C	Sample Result (SR)	C	Spike Added (SA)	%R	Q	M
luminum	75-125	18007.77		12134.55		2427.18	242.0		
Antimony	75-125	124.16		1.25	U	388.35	32.0		P
rsenic	75-125	200.27		100	U	388.35	51.6		P
arium	75-125	354.65		138.26		194.17	111.4		P
Beryllium	75-125	147.16		0.52		194.17	75.5		P
Cadmium	75-125	133.60		0.29	U	194.17	68.8		P
alcium	75-125	11405.09		7424.18		1941.75	205.0		P
Chromium	75-125	2256.23		1562.03		194.17	357.5		P
Cobalt	75-125	142.28		1.02		194.17	72.8		P
opper	75-125	304.63		3.53		388.35	77.5		P
Iron	75-125	3170.49		1265.65		1941.75	98.1		P
Lead	75-125	636.83		272.59		388.35	93.8		P
agnesium	75-125	174019.41		121456.73		1941.75	2706.9		P
anganese	75-125	2323.71		1514.33		388.35	208.4		P
Mercury	75-125	1.06		0.10	U	0.97	109.3		CV
ickel	75-125	298.60		16.05		388.35	72.8		P
otassium	75-125	5205.22		2716.92		1941.75	128.1		P
Selenium	75-125	309.04		5.51		388.35	78.2		P
ilver	75-125	138.60		0.29	U	194.17	71.4		P
odium	75-125	3957.70		777.67		3533.98	90.0		P
Thallium	75-125	232.91		23.93		388.35	53.8		P
Vanadium	75-125	151.28		1.50		194.17	77.1		P
inc	75-125	4529.43		3269.19		388.35	324.5		P
Molybdenum	75-125	134.84		0.29	U	194.17	69.4		P
Lithium	75-125	172.73		1.28		194.17	88.3		P
trontium	75-125	312.30		107.37		194.17	105.5		P
in	75-125	452.94		240.38	U	388.35	116.6		A
ChromiumVI		1.98		120.79		0.49	-24246		A

mments:

6
DUPLICATES

FIELD SAMPLE NO.

SKW-01 D

Client : VERSAR_DIV._24
Site: SAIC_MIN._PROC.

Lab Name: VERSAR_INC. Control No.: 3312 Code: SAICBDAT Batch: 11

Matrix : SOIL

Level (low/med):

Concentration Units (ug/L or mg/kg wet weight): MG/KG

Analyte	Control Limit	Sample (S)	C	Duplicate (D)	C	RPD	Q	M
Aluminum		12134.55		18238.74		40.2		P
Antimony		1.25	U	1.27	U			P
Arsenic		100	U	100	U			P
Barium		138.26		212.09		42.1		P
Beryllium		0.52		0.67		25.2		P
Cadmium		0.29	U	0.29	U			P
Calcium		7424.18		11109.12		39.8		P
Chromium		1562.03		2325.33		39.3		P
Cobalt		1.02		1.52		39.4		P
Copper		3.53		4.25		18.5		P
Iron		1265.65		1966.57		43.4		P
Lead		272.59		401.60		38.3		P
Magnesium		121456.73		188367.60		43.2		P
Manganese		1514.33		2256.19		39.4		P
Mercury		0.10	U	0.10	U			CV
Nickel		16.05		26.33		48.5		P
Potassium		2716.92		4121.00		41.1		P
Selenium		5.51		5.47		0.7		P
Silver		0.29	U	0.29	U			P
Sodium		777.67		1142.95		38.0		P
Thallium		23.93		14.44		49.5		P
Vanadium		1.50		2.02		29.5		P
Zinc		3269.19		4757.14		37.1		P
Molybdenum		0.29	U	0.85				P
Lithium		1.28		2.82		75.1		P
Strontium		107.37		162.00		40.6		P
Tin		240.38	U	245.10	U			A
ChromiumVI		120.79		125.33		3.7		A

FORM VI - IN

2A
INITIAL AND CONTINUING CALIBRATION VERIFICATION

Client : VERSAR_DIV._24______ Site: SAIC_MIN._PROC.______

Lab Name: VERSAR_INC. Control No.: 3312____ Code: SAICBDAT Batch: 11_____

nitial Calibration Source: VARIOUS_________

Continuing Calibration Source: VARIOUS______

Concentration Units: ug/L

Analyte	Initial Calibration			Continuing Calibration					M
	True	Found	%R(1)	True	Found	%R(1)	Found	%R(1)	
Aluminum__	___500.0	__486.59	_97.3	___500.0	__484.09	_96.8	__520.77	104.2	__
ntimony__	___500.0	__509.51	101.9	___500.0	__512.94	102.6	__536.49	107.3	P_
rsenic___	___500.0	__515.15	103.0	___500.0	__493.95	_98.8	__509.92	102.0	P_
Barium____	___500.0	__515.41	103.1	___500.0	__516.87	103.4	__533.67	106.7	P_
eryllium_	___500.0	__506.85	101.4	___500.0	__511.55	102.3	__528.71	105.7	P_
admium___	___500.0	__519.18	103.8	___500.0	__520.10	104.0	__533.33	106.7	P_
Calcium___	_20000.0	19879.57	_99.4	_20000.0	19657.87	_98.3	20301.93	101.5	P_
Chromium__	___500.0	__525.82	105.2	___500.0	__524.43	104.9	__538.20	107.6	P_
Cobalt____	___500.0	__523.43	104.7	___500.0	__525.02	105.0	__541.57	108.3	P_
Copper____	___500.0	__512.65	102.5	___500.0	__519.93	104.0	__536.13	107.2	P_
Iron______	___500.0	__499.62	_99.9	___500.0	__499.41	_99.9	__510.18	102.0	P_
ead______	__1000.0	_1050.80	105.1	__1000.0	_1024.83	102.5	_1046.99	104.7	P_
Magnesium_	___500.0	__507.16	101.4	___500.0	__513.65	102.7	__535.78	107.2	P_
Manganese_	___500.0	__508.13	101.6	___500.0	__510.90	102.2	__531.67	106.3	P_
ercury___	_____5.0	____4.70	_94.0	_____5.0	____4.76	_95.2	____4.58	_91.6	CV
Nickel____	___500.0	__525.50	105.1	___500.0	__526.53	105.3	__544.87	109.0	P_
Potassium_	_20000.0	19292.34	_96.5	_20000.0	18646.10	_93.2	18953.73	_94.8	P_
elenium__	__2000.0	_1961.63	_98.1	__2000.0	_1949.50	_97.5	_2010.45	100.5	P_
ilver____	___500.0	__512.59	102.5	___500.0	__500.16	100.0	__523.76	104.8	P_
Sodium____	_20000.0	20307.73	101.5	_20000.0	20043.53	100.2	20504.95	102.5	P_
Thallium__	__2000.0	_1863.56	_93.2	__2000.0	_2066.29	103.3	_1825.27	_91.3	P_
anadium__	___500.0	__501.87	100.4	___500.0	__502.16	100.4	__523.90	104.8	P_
Zinc______	___500.0	__506.36	101.3	___500.0	__497.85	_99.6	__517.21	103.4	P_
Molybdenum	__2000.0	_1940.87	_97.0	__2000.0	_1922.88	_96.1	_1989.87	_99.5	P_
ithium___	__2000.0	_2080.94	104.0	__2000.0	_2064.49	103.2	_2117.12	105.9	P_
Strontium_	__2000.0	_2056.68	102.8	__2000.0	_2094.61	104.7	_2179.57	109.0	P_
Tin_______	_25000.0	24667.38	_98.7	_25000.0	25369.21	101.5	25369.21	101.5	A_
hromiumVI	___100.0	__110.85	110.8	___100.0	__111.99	112.0	__111.99	112.0	A_

(1) Control Limits: Mercury and Furnace AA Metals 80-120; ICP Metals 90-110;

2A

INITIAL AND CONTINUING CALIBRATION VERIFICATION

Client : VERSAR_DIV._24______

Lab Name: VERSAR_INC. Control No.: 3312____

Site: SAIC_MIN._PROC._____

Code: SAICBDAT Batch: 11_____

Initial Calibration Source: VARIOUS__________

Continuing Calibration Source: VARIOUS______

Concentration Units: ug/L

Analyte	Initial Calibration True	Initial Calibration Found	Initial Calibration %R(1)	Continuing Calibration True	Continuing Calibration Found	Continuing Calibration %R(1)	Continuing Calibration Found	Continuing Calibration %R(1)	M
Aluminum				500.0	496.87	99.4	489.45	97.9	P
Antimony				500.0	530.68	106.1	527.68	105.5	P
Arsenic				500.0	517.86	103.6	521.06	104.2	P
Barium				500.0	513.90	102.8	513.12	102.6	P
Beryllium				500.0	507.10	101.4	509.77	102.0	P
Cadmium				500.0	527.13	105.4	510.21	102.0	P
Calcium				20000.0	20256.98	101.3	20003.02	100.0	P
Chromium				500.0	530.33	106.1	523.68	104.7	P
Cobalt				500.0	530.44	106.1	526.83	105.4	P
Copper				500.0	526.57	105.3	516.45	103.3	P
Iron				500.0	498.74	99.7	490.03	98.0	P
Lead				1000.0	1039.38	103.9	1031.54	103.2	P
Magnesium				500.0	511.04	102.2	506.71	101.3	P
Manganese				500.0	516.87	103.4	510.58	102.1	P
Mercury				5.0	4.82	96.4	4.88	97.6	CV
Nickel				500.0	533.88	106.8	520.93	104.2	P
Potassium				20000.0	19855.51	99.3	18843.50	94.2	P
Selenium				2000.0	2063.99	103.2	1977.24	98.9	P
Silver				500.0	530.61	106.1	519.96	104.0	P
Sodium				20000.0	20327.56	101.6	19802.08	99.0	P
Thallium				2000.0	2145.41	107.3	1966.46	98.3	P
Vanadium				500.0	506.08	101.2	498.87	99.8	P
Zinc				500.0	509.66	101.9	499.95	100.0	P
Molybdenum				2000.0	1945.99	97.3	1916.77	95.8	P
Lithium				2000.0	2074.12	103.7	2047.51	102.4	P
Strontium				2000.0	2004.62	100.2	2001.01	100.1	P
Tin	25000.0	25526.70	102.1	25000.0	26870.75	107.5	24854.67	99.4	A
ChromiumVI	50.0	50.69	101.4	50.0	49.65	99.3	50.69	101.4	A

(1) Control Limits: Mercury and Furnace AA Metals 80-120; ICP Metals 90-110;

FORM II (PART 1) - IN

2A

INITIAL AND CONTINUING CALIBRATION VERIFICATION

Client : VERSAR_DIV._24

Lab Name: VERSAR_INC. Control No.: 3312

Site: SAIC_MIN._PROC.

Code: SAICBDAT Batch: 11

Initial Calibration Source: VARIOUS

Continuing Calibration Source: VARIOUS

Concentration Units: ug/L

Analyte	Initial Calibration True	Found	%R(1)	Continuing Calibration True	Found	%R(1)	Found	%R(1)	M
Aluminum				500.0	489.30	97.9	497.74	99.5	P
Antimony				500.0	521.72	104.3	518.36	103.7	P
Arsenic				500.0	518.11	103.6	511.42	102.3	P
Barium				500.0	518.38	103.7	512.51	102.5	P
Beryllium				500.0	514.62	102.9	510.78	102.2	P
Cadmium				500.0	524.23	104.8	524.06	104.8	P
Calcium				20000.0	20201.22	101.0	20141.73	100.7	P
Chromium				500.0	526.00	105.2	527.00	105.4	P
Cobalt				500.0	528.37	105.7	529.92	106.0	P
Copper				500.0	518.01	103.6	519.57	103.9	P
Iron				500.0	498.14	99.6	500.97	100.2	P
Lead				1000.0	1039.34	103.9	1014.70	101.5	P
Magnesium				500.0	511.57	102.3	510.89	102.2	P
Manganese				500.0	510.25	102.0	512.90	102.6	P
Mercury	5.0	4.78	95.6	5.0	4.97	99.4	4.97	99.4	CV
Nickel				500.0	522.89	104.6	538.43	107.7	P
Potassium				20000.0	19033.60	95.2	19316.04	96.6	P
Selenium				2000.0	2009.85	100.5	1992.92	99.6	P
Silver				500.0	519.48	103.9	520.20	104.0	P
Sodium				20000.0	20264.36	101.3	19825.56	99.1	P
Thallium				2000.0	2041.82	102.1	1858.56	92.9	P
Vanadium				500.0	499.88	100.0	503.20	100.6	P
Zinc				500.0	504.09	100.8	505.55	101.1	P
Molybdenum				2000.0	1928.56	96.4	1920.97	96.0	P
Lithium				2000.0	2073.49	103.7	2041.80	102.1	P
Strontium				2000.0	2026.35	101.3	2006.43	100.3	P
Tin				25000.0	24518.66	98.1	25190.68	100.8	A
ChromiumVI	100.0	105.34	105.3	100.0	108.40	108.4	109.42	109.4	A

Control Limits: Mercury and Furnace AA Metals 80-120; ICP Metals 90-110;

2A

INITIAL ANυ CONTINUING CALIBRATION VERIFICATION

:lient : VERSAR_DIV._24______

Site: SAIC_MIN._PROC._____

Lab Name: VERSAR_INC. Control No.: 3312____

Code: SAICBDAT Batch: 11_____

nitial Calibration Source: VARIOUS_________

Continuing Calibration Source: VARIOUS______

Concentration Units: ug/L

Analyte	Initial Calibration True	Initial Calibration Found	Initial Calibration %R(1)	Continuing Calibration True	Continuing Calibration Found	%R(1)	Found	%R(1)	M
Aluminum									__
ntimony									NR
.rsenic									NR
Barium									NR
eryllium									NR
admium									NR
Calcium									NR
hromium									NR
obalt									NR
Copper									NR
ron									NR
ead									NR
Magnesium									NR
Manganese									NR
ercury									NR
Nickel				5.0	4.84	96.8	5.03	100.6	CV
Potassium									NR
elenium									NR
ilver									NR
Sodium									NR
hallium									NR
anadium									NR
Zinc									NR
olybdenum									NR
ithium									NR
Strontium									NR
Tin									NR
hromiumVI									NR
									NR

) Control Limits: Mercury and Furnace AA Metals 80-120; ICP Metals 90-110;

2A
INITIAL AND CONTINUING CALIBRATION VERIFICATION

Client : VERSAR_DIV._24

Site: SAIC_MIN._PROC.

Lab Name: VERSAR_INC. Control No.: 3312

Code: SAICBDAT Batch: 11

Initial Calibration Source: VARIOUS

Continuing Calibration Source: VARIOUS

Concentration Units: ug/L

Analyte	Initial Calibration True	Initial Calibration Found	Initial Calibration %R(1)	Continuing Calibration True	Continuing Calibration Found	Continuing Calibration %R(1)	Continuing Calibration Found	Continuing Calibration %R(1)	M
Aluminum									NR
Antimony									NR
Arsenic									NR
Barium									NR
Beryllium									NR
Cadmium									NR
Calcium									NR
Chromium									NR
Cobalt									NR
Copper									NR
Iron									NR
Lead									NR
Magnesium									NR
Manganese									NR
Mercury				5.0	4.97	99.4			CV
Nickel									NR
Potassium									NR
Selenium									NR
Silver									NR
Sodium									NR
Thallium									NR
Vanadium									NR
Zinc									NR
Molybdenum									NR
Lithium									NR
Strontium									NR
Tin									NR
ChromiumVI									NR

(1) Control Limits: Mercury and Furnace AA Metals 80-120; ICP Metals 90-110;

2A

INITIAL AND CONTINUING CALIBRATION VERIFICATION

Client : VERSAR_DIV._24______

Site: SAIC_MIN._PROC._____

Lab Name: VERSAR_INC. Control No.: 3312____

Code: SAICBDAT Batch: 11_____

Initial Calibration Source: NBS____________

Continuing Calibration Source: NBS__________

Concentration Units: ug/L

Analyte	Initial Calibration True	Initial Calibration Found	%R(1)	Continuing Calibration True	Continuing Calibration Found	%R(1)	Found	%R(1)	M
Aluminum									NR
Antimony									NR
Arsenic									NR
Barium									NR
Beryllium									NR
Cadmium									NR
Calcium									NR
Chromium									NR
Cobalt									NR
Copper									NR
Iron	150000.0	144209.5	_96.1	150000.0	153640.1	102.4	159207.2	106.1	P_
Lead									NR
Magnesium	_50000.0	47511.29	_95.0	_50000.0	49430.42	_98.9	50667.63	101.3	P_
Manganese									NR
Mercury									NR
Nickel									NR
Potassium									NR
Selenium									NR
Silver									NR
Sodium									NR
Thallium									NR
Vanadium									NR
Zinc									NR
Molybdenum									NR
Lithium									NR
Strontium									NR
Tin									NR
ChromiumVI									NR
									__

(1) Control Limits: Mercury and Furnace AA Metals 80-120; ICP Metals 90-110;

FORM II (PART 1) - IN

2A
INITIAL AND CONTINUING CALIBRATION VERIFICATION

Client : VERSAR_DIV._24______

Site: SAIC_MIN._PROC._____

Lab Name: VERSAR_INC. Control No.: 3312____

Code: SAICBDAT Batch: 11_____

Initial Calibration Source: NBS___________

Continuing Calibration Source: NBS__________

Concentration Units: ug/L

Analyte	Initial Calibration True	Initial Calibration Found	Initial Calibration %R(1)	Continuing Calibration True	Continuing Calibration Found	Continuing Calibration %R(1)	Found	%R(1)	M
Aluminum									__
ntimony									NR
rsenic									NR
Barium									NR
eryllium									NR
admium									NR
Calcium									NR
Chromium									NR
obalt									NR
Copper									NR
Iron									NR
ead				150000.0	155939.1	104.0	154414.1	102.9	P_
agnesium									NR
Manganese				50000.0	50899.05	101.8	49796.98	99.6	P_
ercury									NR
ickel									NR
Potassium									NR
elenium									NR
ilver									NR
Sodium									NR
Thallium									NR
anadium									NR
Zinc									NR
Molybdenum									NR
ithium									NR
strontium									NR
Tin									NR
hromiumVI									NR
									NR
									__

) Control Limits: Mercury and Furnace AA Metals 80-120; ICP Metals 90-110;

FORM II (PART 1) - IN

2A

INITIAL AND CONTINUING CALIBRATION VERIFICATION

Client : VERSAR_DIV._24______

Site: SAIC_MIN._PROC._____

Lab Name: VERSAR_INC. Control No.: 3312____

Code: SAICBDAT Batch: 11_____

Initial Calibration Source: NBS____________

Continuing Calibration Source: NBS__________

Concentration Units: ug/L

Analyte	Initial Calibration True	Initial Calibration Found	%R(1)	Continuing Calibration True	Found	%R(1)	Found	%R(1)	M
Aluminum									__
Antimony									NR
Arsenic									NR
Barium									NR
Beryllium									NR
Cadmium									NR
Calcium									NR
Chromium									NR
Cobalt									NR
Copper									NR
Iron									NR
Lead				150000.0	154343.9	102.9	155443.9	103.6	P_
Magnesium									NR
Manganese				50000.0	49988.54	100.0	50208.74	100.4	P_
Mercury									NR
Nickel									NR
Potassium									NR
Selenium									NR
Silver									NR
Sodium									NR
Thallium									NR
Vanadium									NR
Zinc									NR
Molybdenum									NR
Lithium									NR
Strontium									NR
Tin									NR
ChromiumVI									NR
									NR
									__

(1) Control Limits: Mercury and Furnace AA Metals 80-120; ICP Metals 90-110;

4

ICP INTERFERENCE CHECK SAMPLE

Client : VERSAR_DIV._24______ Site: SAIC_MIN._PROC. ______

ab Name: VERSAR_INC. Control No.: 3312____ Code: SAICBDAT Batch: 11______

ICP ID Number: 4-JA_1140___ ICS Source: I.V.____

Concentration Units: ug/L

Analyte	True Sol. A	True Sol. AB	Initial Found Sol. A	Initial Found Sol. AB	Initial Found %R	Final Found Sol. A	Final Found Sol. AB	Final Found %R
Aluminum		500000		486081.4	97.2		492322.2	98.5
Antimony								
Arsenic								
Barium		500		500.6	100.1		512.1	102.4
Beryllium		500		439.3	87.9		454.1	90.8
Cadmium		1000		911.5	91.2		914.7	91.5
Calcium		500000		453735.5	90.7		469440.2	93.9
Chromium		500		506.1	101.2		519.4	103.9
Cobalt		500		443.8	88.8		460.9	92.2
Copper		500		438.7	87.7		448.0	89.6
Iron		200000		176401.9	88.2		180486.3	90.2
Lead		1000		934.7	93.5		944.7	94.5
Magnesium		500000		462475.2	92.5		471794.1	94.4
Manganese		500		453.1	90.6		468.9	93.8
Mercury								
Nickel		1000		904.4	90.4		922.1	92.2
Potassium								
Selenium								
Silver		1000		894.4	89.4		924.9	92.5
Sodium								
Thallium								
Vanadium		500		455.6	91.1		468.1	93.6
Zinc		1000		911.0	91.1		924.0	92.4
Molybdenum								
Lithium								
Strontium								
Tin								
ChromiumVI								

7

LABORATORY CONTROL SAMPLE

Client : VERSAR_DIV._24______

Site: SAIC_MIN._PROC._____

Lab Name: VERSAR_INC. Control No.: 3312____ Code: SAICBDAT Batch: 11_____

Solid LCS Source: ____________

Aqueous LCS Source: METH_SPK__

Analyte	Aqueous (ug/L) True	Aqueous (ug/L) Found	Aqueous (ug/L) %R	Solid (mg/kg) True	Solid (mg/kg) Found	Solid (mg/kg) C	Solid (mg/kg) Limits		Solid (mg/kg) %R
Aluminum__	20000.0	18553.47	_92.8						
Antimony__	_4000.0	_3754.13	_93.9						
Arsenic___	_4000.0	_3753.98	_93.8						
Barium____	_2000.0	_1938.24	_96.9						
Beryllium_	_2000.0	_1821.68	_91.1						
Cadmium___	_2000.0	_1801.84	_90.1						
Calcium___	20000.0	18551.81	_92.8						
Chromium__	_2000.0	_1930.97	_96.5						
Cobalt____	_2000.0	_1828.14	_91.4						
Copper____	_4000.0	_3661.75	_91.5						
Iron______	20000.0	18186.42	_90.9						
Lead______	_4000.0	_3547.81	_88.7						
Magnesium_	20000.0	18640.15	_93.2						
Manganese_	_4000.0	_3627.55	_90.7						
Mercury___	____2.0	____2.00	100.0						
Nickel____	_4000.0	_3625.00	_90.6						
Potassium_	20000.0	17758.18	_88.8						
Selenium__	_4000.0	_3605.31	_90.1						
Silver____	_2000.0	_1683.95	_84.2						
Sodium____	36400.0	35482.25	_97.5						
Thallium__	_4000.0	_3365.77	_84.1						
Vanadium__	_2000.0	_1846.55	_92.3						
Zinc______	_4000.0	_3477.68	_86.9						
Molybdenum	_2000.0	_1722.50	_86.1						
Lithium___	_2000.0	_1955.29	_97.8						
trontium_	_2000.0	_1956.56	_97.8						
Tin_______	_4000.0	_3963.40	_99.1						
ChromiumVI	___50.0	___52.76	105.5						

LABORATORY CONTROL SAMPLE

Client : VERSAR_DIV._24 Site: SAIC_MIN._PROC.

Lab Name: VERSAR_INC. Control No.: 3312 Code: SAICBDAT Batch: 11

Solid LCS Source:

Aqueous LCS Source: METH_SPK

Analyte	Aqueous (ug/L) True	Aqueous (ug/L) Found	Aqueous (ug/L) %R	Solid (mg/kg) True	Solid (mg/kg) Found	C	Limits		%R
Aluminum	20000.0	18070.79	90.4						
Antimony	4000.0	3644.11	91.1						
Arsenic	4000.0	3634.48	90.9						
Barium	2000.0	1907.09	95.4						
Beryllium	2000.0	1870.05	93.5						
Cadmium	2000.0	1796.10	89.8						
Calcium	20000.0	18179.14	90.9						
Chromium	2000.0	1918.19	95.9						
Cobalt	2000.0	1822.63	91.1						
Copper	4000.0	3644.77	91.1						
Iron	20000.0	18093.26	90.5						
Lead	4000.0	3519.00	88.0						
Magnesium	20000.0	18509.09	92.5						
Manganese	4000.0	3605.74	90.1						
Mercury	2.0	2.02	101.0						
Nickel	4000.0	3647.50	91.2						
Potassium	20000.0	16606.78	83.0						
Selenium	4000.0	3604.95	90.1						
Silver	2000.0	1655.60	82.8						
Sodium	36400.0	34654.31	95.2						
Thallium	4000.0	3069.50	76.7						
Vanadium	2000.0	1823.62	91.2						
Zinc	4000.0	3503.19	87.6						
Molybdenum	2000.0	1655.99	82.8						
Lithium	2000.0	1900.71	95.0						
Strontium	2000.0	1925.18	96.3						
Tin	4000.0	4357.86	108.9						
ChromiumVI	50.0	52.73	105.5						

NORGANIC ANALYSES DATA SH__T

FIELD SAMPLE NO.

SKW-01

Client : VERSAR_DIV._24______ Site: SAIC_MIN._PROC.

Lab Name: VERSAR_INC. Control No.: 3312____ Code: SAICBDAT Batch: 11______

Matrix : TCLP EXTRACT____

Lab Sample ID: T28867___

Level (low/med): ________

Date Received: 08/16/90_

Concentration Units (ug/L or mg/kg dry weight): UG/L_

CAS No.	Analyte	Concentration	C	Q	M
7429-90-5_	Aluminum__	__________1390	_	______	P_
7440-36-0_	Antimony__	__________22.6	_	______	P_
7440-38-2_	Arsenic___	___________800	U	__E___	P_
7440-39-3_	Barium____	___________598	_	______	P_
7440-41-7_	Beryllium_	___________1.0	U	______	P_
7440-43-9_	Cadmium___	___________3.0	U	______	P_
7440-70-2_	Calcium___	_________56200	_	______	P_
7440-47-3_	Chromium__	__________2070	_	______	P_
7440-48-4_	Cobalt____	___________3.0	U	______	P_
7440-50-8_	Copper____	___________3.0	U	______	P_
7439-89-6_	Iron______	___________4.0	U	______	P_
7439-92-1_	Lead______	__________30.2	_	______	P_
7439-95-4_	Magnesium_	________954000	_	______	P_
7439-96-5_	Manganese_	__________5080	_	______	P_
7439-97-6_	Mercury___	__________0.20	U	______	CV
7440-02-0_	Nickel____	__________33.2	_	______	P_
7440-09-7_	Potassium_	_________26300	_	______	P_
7782-49-2_	Selenium__	__________68.6	_	______	P_
7440-22-4_	Silver____	___________3.0	U	______	P_
7440-23-5_	Sodium____	_________10500	_	______	P_
7440-28-0_	Thallium__	__________57.0	U	______	P_
7440-62-2_	Vanadium__	__________10.9	_	______	P_
7440-66-6_	Zinc______	__________1630	_	______	P_
__________	Molybdenum	___________8.2	_	______	P_
__________	Lithium___	__________54.5	_	______	P_
__________	Strontium_	___________698	_	______	P_
__________	Tin_______	__________2500	U	______	A_
__________	ChromiumVI	___________470	_	______	A_
__________	__________	______________	_	______	__

Color Before: YELLOW___ Clarity Before: CLEAR_ Texture: ______

Color After : COLORLESS Clarity After: CLEAR_ Artifacts: ______

Comments:
TCLP_EXTRACT_RESULTS;_"E" - SEVERE MATRIX INTERFERENCE________________

3
BLANKS

Client : VERSAR_DIV._24______ Site: SAIC_MIN._PROC._____

Lab Name: VERSAR_INC. Control No.: 3312____ Code: SAICBDAT Batch: 11_____

Preparation Blank Matrix: TCLP EXTRACT______

Preparation Blank Concentration Units (ug/L or mg/kg): UG/L_

Analyte	Initial Calib. Blank (ug/L)	C	Continuing Calibration Blank (ug/L) 1	C	2	C	3	C	Preparation Blank	C	M
Aluminum			11.0	U					60.7		P
ntimony			13.0	U					16.0		P
Arsenic			11.0	U					11.0	U	P
Barium			1.0	U					150.7		P
eryllium			1.0	U					1.0	U	P
Cadmium			3.0	U					3.0	U	P
Calcium			7.0	U					66.7		P
hromium			2.0	U					6.6		P
obalt			3.0	U					3.0	U	P
Copper			3.9						8.9		P
ron			4.8						70.4		P
ead			23.0	U					23.0	U	P
Magnesium			2.9						33.4		P
Manganese			2.0	U					4.5		P
ercury			0.2	U					0.2	U	CV
Nickel			5.0	U					13.4		P
Potassium			447.5						376.0	U	P
elenium			24.0	U					24.0	U	P
Silver			3.0	U					3.0	U	P
Sodium			14.0	U					364.7		P
hallium			57.0	U					57.0	U	P
anadium			2.0	U					2.0	U	P
Zinc			2.0	U					34.1		P
olybdenum			3.0	U					3.0	U	P
ithium			2.0	U					2.0	U	P
Strontium			1.0	U					3.3		P
Tin	2500.0	U	2500.0	U	2500.0	U	2500.0	U	2500.0	U	A
hromiumVI	10.0	U	10.0	U	10.0	U			10.0	U	A

FORM III - IN

3
BLANKS

Client : VERSAR_DIV._24 Site: SAIC_MIN._PROC.

Lab Name: VERSAR_INC. Control No.: 3312 Code: SAICBDAT Batch: 11

Preparation Blank Matrix: TCLP FILTRATION BLANK

Preparation Blank Concentration Units (ug/L or mg/kg): UG/L

Analyte	Initial Calib. Blank (ug/L)	C	Continuing Calibration Blank (ug/L) 1	C	2	C	3	C	Preparation Blank	C	M
Aluminum			11.0	U	28.9				34.0		P
Antimony			13.0	U	13.0	U			57.8		P
Arsenic			11.0	U	11.0	U			11.0	U	P
Barium			1.0	U	1.0	U			79.3		P
Beryllium			1.6		1.3				1.0	U	P
Cadmium			3.0	U	3.0	U			3.0	U	P
Calcium			7.0	U	7.0	U			7.0	U	P
Chromium			2.0	U	3.7				6.1		P
Cobalt			3.0	U	3.0	U			3.0	U	P
Copper			3.0	U	3.0	U			7.3		P
Iron			28.3		20.6				29.8		P
Lead			23.0	U	23.0	U			23.0	U	P
Magnesium			10.7		6.2				31.8		P
Manganese			2.3		2.0	U			2.8		P
Mercury	0.2	U	0.2	U	0.2	U	0.2	U	0.2	U	CV
Nickel			5.0	U	12.5				9.8		P
Potassium			768.8		1696.4				376.0	U	P
Selenium			24.0	U	24.0	U			24.0	U	P
Silver			3.0	U	3.0	U			3.0	U	P
Sodium			14.0	U	19.9				2171.2		P
Thallium			57.0	U	57.0	U			57.0	U	P
Vanadium			2.0	U	3.2				2.0	U	P
Zinc			2.0	U	2.0	U			72.7		P
Molybdenum			3.0	U	3.0	U			3.0	U	P
Lithium			2.0	U	2.0	U			2.0	U	P
Strontium			1.0	U	1.0	U			5.8		P
Tin			2500.0	U					2500.0	U	A
ChromiumVI	10.0	U	10.0	U	10.0	U			10.0	U	A

FORM III - IN

5A
SPIKE SAMPLE RECOVERY

FIELD SAMPLE NO.

SKW-01 S

Client : VERSAR_DIV._24______ Site: SAIC_MIN._PROC.

Lab Name: VERSAR_INC. Control No.: 3312____ Code: SAICBDAT Batch: 11_____

Matrix : TCLP EXTRACT___

Level (low/med): _____

Concentration Units (ug/L or mg/kg dry weight): UG/L_

Analyte	Control Limit %R	Spiked Sample Result (SSR)	C	Sample Result (SR)	C	Spike Added (SA)	%R	Q	M
Aluminum	75-125	19559.21		1392.13		25000.00	72.7		P
Antimony	75-125	3632.03		22.60		4000.00	90.2		P
Arsenic	75-125	2897.58		800	U	4000.00	72.4		P
Barium	75-125	2687.39		598.43		2000.00	104.4		P
Beryllium	75-125	1900.58		1.00	U	2000.00	95.0		P
Cadmium	75-125	1651.68		3.00	U	2000.00	82.6		P
Calcium	75-125	76880.43		56154.44		20000.00	103.6		P
Chromium	75-125	4022.11		2069.42		2000.00	97.6		P
Cobalt	75-125	1728.61		3.00	U	2000.00	86.4		P
Copper	75-125	3567.64		3.00	U	4000.00	89.2		P
Iron	75-125	17285.09		4.00	U	20000.00	86.4		P
Lead	75-125	3383.33		30.19		4000.00	83.8		P
Magnesium	75-125	216720.00		353571.71		20000.00	-3684.3		P
Manganese	75-125	8912.08		5076.49		4000.00	95.9		P
Mercury	75-125	1.96		0.20	U	2.00	98.0		CV
Nickel	75-125	3478.48		33.16		4000.00	86.1		P
Potassium	75-125	45238.63		26347.01		20000.00	94.5		P
Selenium	75-125	3824.35		58.56		4000.00	93.9		P
Silver	75-125	1623.74		3.00	U	2000.00	81.2		P
Sodium	75-125	46437.08		10525.04		36400.00	98.7		P
Thallium	75-125	3004.47		57.00	U	4000.00	75.1		P
Vanadium	75-125	1819.82		10.90		2000.00	90.4		P
Zinc	75-125	5034.35		1634.89		4000.00	85.0		P
Molybdenum	75-125	1679.48		8.16		2000.00	83.6		P
Lithium	75-125	2065.29		54.54		2000.00	100.5		P
Strontium	75-125	2738.59		697.98		2000.00	102.0		P
Tin	75-125	4021.85		2500.00	U	4000.00	100.5		A
ChromiumVI	75-125	527.28		470.29		50.00	114.0		A

Comments:

TCLP_EXTRACT_RESULTS

FORM V (PART 1) - IN

6

DUPLICATES

FIELD SAMPLE NO.

SKW-01 D

Client : VERSAR_DIV._24______ Site: SAIC_MIN._PROC.

Lab Name: VERSAR_INC. Control No.: 3312____ Code: SAICBDAT Batch: 11_____

Matrix : TCLP EXTRACT____

Level (low/med): _____

Concentration Units (ug/L or mg/kg dry weight): UG/L_

Analyte	Control Limit	Sample (S)	C	Duplicate (D)	C	RPD	Q	M
Aluminum		1392.10		1761.80		23.4		P
Antimony		22.60		13.40		51.1		P
Arsenic		800	U	800	U			P
Barium		598.40		798.40		28.6		P
Beryllium		1.00	U	1.00	U			P
Cadmium		3.00	U	3.00	U			P
Calcium		56154.40		62662.80		11.0		P
Chromium		2069.40		2307.40		10.9		P
Cobalt		3.00	U	3.00	U			P
Copper		3.00	U	3.00	U			P
Iron		4.00	U	4.00	U			P
Lead		30.20		28.20		6.8		P
Magnesium		953571.70		1136300.00		17.5		P
Manganese		5076.50		5661.50		10.9		P
Mercury		0.20	U	0.20	U			CV
Nickel		33.20		36.10		8.4		P
Potassium		25347.00		29511.40		11.3		P
Selenium		68.60		47.00		37.4		P
Silver		3.00	U	3.00	U			P
Sodium		10525.00		12367.00		16.1		P
Thallium		57.00	U	57.00	U			P
Vanadium								NR
Zinc		1634.90		1840.10		11.8		P
Molybdenum		8.20		12.20		39.2		P
Lithium		54.50		62.40		13.5		P
Strontium								NR
Tin		2500.00	U	2500.00	U			A
ChromiumVI		470.30		493.10		4.7		A

FORM VI - IN

9

ICP SERIAL DILUTION

FIELD SAMPLE NO.

SKW-01

Client : VERSAR_DIV._24______ Site: SAIC_MIN._PROC.

Lab Name: VERSAR_INC. Control No.: 3312____ Code: SAICBDAT Batch: 11_____

Matrix : TCLP EXTRACT___

Level (low/med): _____

Concentration Units: ug/L

Analyte	Initial Sample Result (I)	C	Serial Dilution Result (S)	C	% Difference	Q	M
Aluminum	1392.10		1417.80		1.80		P
Antimony	22.60		65.20		188.5		P
Arsenic	11.00	U	55.00	U			NR
Barium	598.40		596.20		0.40		P
Beryllium	1.00	U	5.00	U			NR
Cadmium	3.00	U	15.00	U			NR
Calcium	56154.40		58851.70		4.80		P
Chromium	2069.40		2142.00		3.50		P
Cobalt	3.00	U	15.00	U			NR
Copper	3.00	U	15.00	U			NR
Iron	4.00	U	20.00	U			NR
Lead	30.20		115.00	U			NR
Magnesium	953571.70		953494.60		0.00		P
Manganese	5076.50		5273.40		3.90		P
Mercury							CV
Nickel	33.20		43.50		31.00		P
Potassium	26347.00		28262.20		7.30		P
Selenium	68.60		120.00	U			NR
Silver	3.00	U	15.00	U			NR
Sodium	10525.00		10484.10		0.40		P
Thallium	57.00	U	285.00	U			NR
Vanadium	10.90		17.00		56.00		P
Zinc	1634.90		1753.00		7.20		P
Molybdenum	8.20		15.00	U			NR
Lithium	54.50		36.10		33.80		P
Strontium	698.00		691.40		0.90		P
Tin							P
ChromiumVI							P
							A

1

ORGANIC ANALYSES DATA SHEET

FIELD SAMPLE NO.

SKW-01

Client : VERSAR_DIV._24______ Site: SAIC_MIN._PROC.

Lab Name: VERSAR_INC. Control No.: 3312____ Code: SAICBDAT Batch: 11_____

Matrix : APLP EXTRACT___

Lab Sample ID: A28867___

Level (low/med): ________

Date Received: 08/16/90_

Concentration Units (ug/L or mg/kg dry weight): UG/L_

CAS No.	Analyte	Concentration	C	Q	M
7429-90-5_	Aluminum__	109	_		P_
7440-36-0_	Antimony__	51.6	_		P_
7440-38-2_	Arsenic___	11.0	U		P_
7440-39-3_	Barium____	254	_		P_
7440-41-7_	Beryllium_	1.0	U		P_
7440-43-9_	Cadmium___	3.0	U		P_
7440-70-2_	Calcium___	41400	_		P_
7440-47-3_	Chromium__	1550	_		P_
7440-48-4_	Cobalt____	3.0	U		P_
7440-50-8_	Copper____	3.0	U		P_
7439-89-6_	Iron______	40.9	_		P_
7439-92-1_	Lead______	23.0	U		P_
7439-95-4_	Magnesium_	21500	_		P_
7439-96-5_	Manganese_	2.0	U		P_
7439-97-6_	Mercury___	0.20	U		CV
7440-02-0_	Nickel____	7.2	_		P_
7440-09-7_	Potassium_	38000	_		P_
7782-49-2_	Selenium__	53.4	_		P_
7440-22-4_	Silver____	3.0	U		P_
7440-23-5_	Sodium____	10100	_		P_
7440-28-0_	Thallium__	57.0	U		P_
7440-62-2_	Vanadium__	3.9	_		P_
7440-66-6_	Zinc______	62.0	_		P_
	Molybdenum	10.8	_		P_
	Lithium___	155	_		P_
	Strontium_	646	_		P_
	Tin_______	2500	U		A_
	ChromiumVI	1350	_		A_
			_		__

Color Before: YELLOW___ Clarity Before: CLEAR_ Texture: ______

Color After : COLORLESS Clarity After: CLEAR_ Artifacts: ______

Comments:

APLP_EXTRACT_RESULTS

3
BLANKS

Client : VERSAR_DIV._24______ Site: SAIC_MIN._PROC._____

Lab Name: VERSAR_INC. Control No.: 3312____ Code: SAICBDAT Batch: 11_____

reparation Blank Matrix: APLP EXTRACT______

Preparation Blank Concentration Units (ug/L or mg/kg): UG/L_

Analyte	Initial Calib. Blank (ug/L)	C	Continuing Calibration Blank (ug/L) 1	C	2	C	3	C	Prepa- ration Blank	C	M
Aluminum									58.5		P
ntimony									13.0	U	P
Arsenic									11.0	U	P
Barium									64.9		P
eryllium									1.0	U	P
Cadmium									3.0	U	P
Calcium									140.3		P
Chromium									2.0	U	P
Cobalt									3.0	U	P
Copper									14.0		P
ron									42.7		P
Lead									23.0	U	P
Magnesium									110.4		P
Manganese									4.3		P
ercury			0.2	U	0.2	U			0.2	U	CV
Nickel									9.0		P
Potassium									376.0	U	P
Selenium									24.0	U	P
Silver									3.0	U	P
Sodium									494.8		P
hallium									101.5		P
Vanadium									2.0	U	P
Zinc									63.7		P
olybdenum									3.0	U	P
ithium									2.0	U	P
Strontium									2.4		P
Tin									2500.0	U	A
hromiumVI									10.0	U	NR

FORM III - IN

3

BLANKS

Client : VERSAR_DIV._24______

Site: SAIC_MIN._PROC.______

Lab Name: VERSAR_INC. Control No.: 3312____ Code: SAICBDAT Batch: 11_____

Preparation Blank Matrix: APLP FILTRATION BLANK

Preparation Blank Concentration Units (ug/L or mg/kg): UG/L_

Analyte	Initial Calib. Blank (ug/L)	C	Continuing Calibration Blank (ug/L) 1	C	2	C	3	C	Preparation Blank	C	M
Aluminum									30.9		P
Antimony									13.0	U	P
Arsenic									11.0	U	P
Barium									15.8		P
Beryllium									1.1		P
Cadmium									3.0	U	P
Calcium									73.6		P
Chromium									2.5		P
Cobalt									3.0	U	P
Copper									3.1		P
Iron									22.2		P
Lead									23.0	U	P
Magnesium									12.3		P
Manganese									2.0	U	P
Mercury									0.2	U	CV
Nickel									5.0	U	P
Potassium									602.1		P
Selenium									24.0	U	P
Silver									3.0	U	P
Sodium									502.0		P
Thallium									106.5		P
Vanadium									2.0	U	P
Zinc									30.8		P
Molybdenum									3.0	U	P
Lithium									2.0	U	P
Strontium									1.0	U	P
Tin									2500.0	U	A
ChromiumVI									10.0	U	NR

FORM III - IN

ICP SERIAL DILUTION

FIELD SAMPLE NO.

SKW-01

lient : VERSAR_DIV._24______ Site: SAIC_MIN._PROC.

ab Name: VERSAR_INC. Control No.: 3312____ Code: SAICBDAT Batch: 11_____

Matrix : SOIL___________ Level (low/med): _____

Concentration Units: ug/L

Analyte	Initial Sample Result (I)	C	Serial Dilution Result (S)	C	% Difference	Q	M
Aluminum	126199.40		132648.40		5.10		P
Antimony	13.00	U	65.00	U			NR
Arsenic	11.00	U	55.00	U			NR
Barium	1437.90		1520.00		5.70		P
Beryllium	5.40		7.70		42.60		P
Cadmium	3.00	U	15.00	U			NR
Calcium	77211.50		85237.40		10.40		P
Chromium	16245.10		17957.10		10.50		P
Cobalt	10.60		15.00	U			NR
Copper	36.80		53.00		44.00		P
Iron	13162.80		14533.30		10.40		P
Lead	2835.00		3281.80		15.80		P
Magnesium	252630.00		254678.00		0.80		P
Manganese	15749.00		17393.60		10.40		P
Mercury							CV
Nickel	167.00		200.20		19.90		P
Potassium	28255.90		27414.70		3.00		P
Selenium	57.30		120.00	U			NR
Silver	3.00	U	15.00	U			NR
Sodium	8087.70		8474.70		4.80		P
Thallium	248.90		665.60		167.4		P
Vanadium	15.60		22.00		41.00		P
Zinc	33999.60		38693.50		13.80		P
Molybdenum	3.00	U	15.00	U			NR
Lithium	13.30		22.70		70.70		P
Strontium	1116.70		1174.30		5.20		P
Tin							P
ChromiumVI							A

FORM IX - IN

5A
SPIKE SAMPLE RECOVERY

FIELD SAMPLE NO.

SKW-01 S

Client : VERSAR_DIV._24______ Site: SAIC_MIN._PROC.

Lab Name: VERSAR_INC. Control No.: 3312____ Code: SAICBDAT Batch: 11_____

Matrix : APLP EXTRACT___

Level (low/med): _____

Concentration Units (ug/L or mg/kg dry weight): UG/L_

Analyte	Control Limit %R	Spiked Sample Result (SSR)	C	Sample Result (SR)	C	Spike Added (SA)	%R	Q	M
Aluminum	75-125	17801.25		109.00		25000.00	70.8		P
Antimony	75-125	3681.18		51.56		4000.00	90.7		P
Arsenic	75-125	3653.92		11.00	U	4000.00	91.3		P
Barium	75-125	2135.71		253.86		2000.00	94.1		P
Beryllium	75-125	1800.28		1.00	U	2000.00	90.0		P
Cadmium	75-125	1736.91		3.00	U	2000.00	86.8		P
Calcium	75-125	55396.86		41409.75		20000.00	69.9		P
Chromium	75-125	3274.78		1550.57		2000.00	86.2		P
Cobalt	75-125	1794.08		3.00	U	2000.00	89.7		P
Copper	75-125	3634.00		3.00	U	4000.00	90.8		P
Iron	75-125	17567.19		40.88		20000.00	87.6		P
Lead	75-125	3396.14		23.00	U	4000.00	84.9		P
Magnesium	75-125	37796.41		21491.59		20000.00	81.5		P
Manganese	75-125	3552.28		2.00	U	4000.00	88.8		P
Mercury	75-125	2.08		0.20	U	2.00	104.0		CV
Nickel	75-125	3534.69		7.16		4000.00	88.2		P
Potassium	75-125	53095.03		37970.15		20000.00	75.6		P
Selenium	75-125	3691.65		53.43		4000.00	91.0		P
Silver	75-125	1688.80		3.00	U	2000.00	84.4		P
Sodium	75-125	43506.44		10117.73		36400.00	91.7		P
Thallium	75-125	3032.38		57.00	U	4000.00	75.8		P
Vanadium	75-125	1803.59		3.86		2000.00	90.0		P
Zinc	75-125	3429.03		61.97		4000.00	84.2		P
Molybdenum	75-125	1675.83		10.85		2000.00	83.2		P
Lithium	75-125	2065.03		155.46		2000.00	95.5		P
Strontium	75-125	2447.60		646.07		2000.00	90.1		P
Tin	75-125	3349.82		2500.00	U	4000.00	83.7		A
ChromiumVI	75-125	1464.84		1350.88		50.00	227.9		A

Comments:

APLP_EXTRACT_RESULTS

FORM V (PART 1) - IN

6
DUPLICATES

FIELD SAMPLE NO.

SKW-01 D

Client : VERSAR_DIV._24______ Site: SAIC_MIN._PROC.

Lab Name: VERSAR_INC. Control No.: 3312____ Code: SAICBDAT Batch: 11_____

Matrix : APLP EXTRACT____

Level (low/med): _____

Concentration Units (ug/L or mg/kg dry weight): UG/L_

Analyte	Control Limit	Sample (S)	C	Duplicate (D)	C	RPD	Q	M
Aluminum		109.00		49.20		75.6		P
Antimony		51.60		49.50		4.2		P
Arsenic		11.00	U	11.00	U			P
Barium		253.90		210.80		18.5		P
Beryllium		1.00	U	1.00	U			P
Cadmium		3.00	U	3.00	U			P
Calcium		41409.80		34466.70		18.3		P
Chromium		1550.60		1291.90		18.2		P
Cobalt		3.00	U	3.00	U			P
Copper		3.00	U	3.00	U			P
Iron		40.90		51.50		22.9		P
Lead		23.00	U	23.00	U			P
Magnesium		21491.60		18012.80		17.6		P
Manganese		2.00	U	3.00				P
Mercury		0.20	U	0.20	U			CV
Nickel		7.20		5.00	U			P
Potassium		37970.20		32062.40		16.9		P
Selenium		53.40		72.70		30.6		P
Silver		3.00	U	3.00	U			P
Sodium		10117.70		8353.50		19.1		P
Thallium		57.00	U	57.00	U			P
Vanadium		3.90		3.50		10.8		P
Zinc		62.00		59.40		4.3		P
Molybdenum		10.80		8.40		25.0		P
Lithium		155.50		129.90		17.9		P
Strontium		646.10		538.80		18.1		P
Tin		2500.00	U	2500.00	U			A
ChromiumVI		1350.90		1396.50		3.3		A

FORM VI - IN

ICP SERIAL DILUTION

FIELD SAMPLE NO.

SKW-01

Client : VERSAR_DIV._24______ Site: SAIC_MIN._PROC.

Lab Name: VERSAR_INC. Control No.: 3312____ Code: SAICBDAT Batch: 11_____

Matrix : APLP EXTRACT___

Level (low/med): _____

Concentration Units: ug/L

Analyte	Initial Sample Result (I)	C	Serial Dilution Result (S)	C	% Difference	Q	M
Aluminum	109.00		116.20		6.60		P
Antimony	51.60		70.00		35.70		P
Arsenic	11.00	U	55.00	U			NR
Barium	253.90		257.20		1.30		P
Beryllium	1.00	U	5.00	U			NR
Cadmium	3.00	U	18.00				NR
Calcium	41409.80		43118.70		4.10		P
Chromium	1550.60		1618.40		4.40		P
Cobalt	3.00	U	15.00	U			NR
Copper	3.00	U	16.60				NR
Iron	40.90		41.20		0.70		P
Lead	23.00	U	115.00	U			NR
Magnesium	21491.60		22929.80		6.70		P
Manganese	2.00	U	10.00	U			NR
Mercury							CV
Nickel	7.20		25.00	U			NR
Potassium	37970.20		42406.70		11.70		P
Selenium	53.40		120.00	U			NR
Silver	3.00	U	15.00	U			NR
Sodium	10117.70		10166.40		0.50		P
Thallium	57.00	U	503.70				NR
Vanadium	3.90		10.00	U			NR
Zinc	62.00		75.20		21.30		P
Molybdenum	10.80		15.00	U			NR
Lithium	155.50		140.00		10.00		P
Strontium	646.10		653.40		1.10		P
Tin							P
ChromiumVI							A

00035

3

Attachment 3

General Engineering Lab Results

U.S. NELS, INC.

SOURCE SAMPLING FOR HEXAVALENT CHROME EMISSIONS

MACALLOY CORPORATION

FURNACE NO. 15

CHARLESTON, SOUTH CAROLINA

OCTOBER 1991

Dated: November 12, 1991

Submitted By:

Steven W. Brockel, P.E.
Senior Consultant

1701 MARYLAND AVENUE • WILMINGTON DE 19805 • (302)

1.0 PROCESS DESCRIPTION

Macalloy Corporation of Charleston, South Carolina, is a smelting facility that manufactures ferrochrome. The raw material used in this process are chromite ores, by-product coke, and gravel, which are received by rail, ship or barge.

Macalloy has two electric smelting furnaces numbered 14 and 15. Emissions from the furnaces are controlled by two electrostatic precipitators. Originally (1976), two 50,000 acfm baghouses were used to collect emissions during tapping operations which occur fifteen times per day and last approximately 30 - 40 minutes each tap.

In 1988 a third baghouse was installed, the furnace canopy hoods were extended, and auxiliary dust hoods were added to capture emissions escaping from the main furnace canopy hoods. Each furnace has two auxiliary hood segments. The two segments for one furnace are located on opposite sides of the furnace. The hood opening consists of slots which extend around the edge of the canopy hood (see attached schematic diagram).

The three baghouses provided a total of 150,000 acfm of capacity for the two furnaces, or 75,000 acfm for each furnace. The distribution of flow for one of the furnaces is 25,000 acfm total for the auxiliary hood segments and 50,000 acfm for the tap hood. With only one furnace in operation and three baghouses in operation, the hoods will have higher air flows than with two furnaces operating. The air flows through the hoods and baghouses were recently measured with only one No. 15 furnace in operation. Based on these tests, it was determined that the flow through each of the baghouses was significantly lower than the design flow. Operating with only two baghouses would achieve essentially the same flow as operating with three baghouses. With one furnace and two baghouses operating, the flow through the auxiliary hoods will be 30,000 acfm and the flow through the tap hoods will be 70,000 acfm. These hood flows are effective in controlling the emissions from the furnace.

To upgrade the fume collection system for a two furnace operation, two additional baghouses of 50,000 acfm each are to be installed to operate with the No. 14 furnace. Two of the existing baghouses will be used for control on No. 15 furnace. Each furnace will have two dedicated baghouses with a total air flow of 100,000 acfm per furnace.

	Existing Two Furnace Operation	Proposed Two Furnace Operation	Increase
Auxiliary Hoods per Furnace	25,000	30,000	20%
Tap Hood per Furnace	50,000	70,000	40%
Flow per Furnace	75,000	100,000	33%
Total Both Furnaces	150,000	200,000	33%

2.0 DUST CHARACTERISTICS

A typical chemical analysis of the dust collected by the present system is attached. Unlike the dust collected in the main furnace system, i.e. the electrostatic precipitators, this secondary dust contains no hexavalent chromium and is not considered to be a hazardous waste. Recent TCLP tests (3 on 1/12/90 and 3 on 12/10/90) indicated less than 0.1 mg/l for hexavalent chromium.

3.0 EMISSION ESTIMATES

The present system of three baghouses collect approximately 2100 lbs of dust per day when two furnaces are operating. After installation of two baghouses for No. 14 furnace along with the operations of two existing baghouses for No. 15 furnace, the increased flow into the hoods will increase the amount of fumes and therefore the amount of particulate collected. An increase of dust collection of 40% is assumed.

The increased dust collected is therefore:

1.4 x 2100 lbs/day = 2940 lbs/day

The amount of dust collected per hour is:

$$\frac{2940 \text{ lbs/day}}{24 \text{ hrs}} = 122.5 \text{ lbs/hr}$$

Assume the collection efficiency of the baghouses is 98%. The emissions after controls would be:

$$122.5 \text{ lbs} \times .02 = 2.45 \text{ lbs/hr}$$

The emissions associated with the two new baghouses for No. 14 furnace is:

before controls emissions $= \frac{122.5 \text{ lbs/hr}}{2} = 61.25$ lbs/hr

after controls emissions $= \frac{2.45}{2}$ lbs/hr $= 1.23$ lbs/hr

No. 7489

9-17-91

TABLE 1

SUMMARY OF TEST RESULTS FOR HEXAVALENT CHROME EMISSIONS
FURNACE NO. 15

MACALLOY CORPORATION
CHARLESTON, SOUTH CAROLINA

Date of Test	10/9/91	10/9/91	10/9/91
Sampling Location	Furnace No. 15 Stack		
Test Run Number	M-15-1HC	M-15-2HC	M-15-3HC
Operating Data (1):			
Megawatt Load, MW	33.9	34.0	33.75
Temp. Into ESP, degrees F	183	178	190
Temp. Into Cond. Tower, degrees F	555	583	627
I.D. Fan Opening, %	95	84	83
Opacity, %	4.7	5.2	5.7
Flue Gas Characteristics:			
Gas Flow, dscfm	152,012	139,616	144,400
Gas Flow, acfm	200,054	184,004	191,523
Temperature, degrees F	172	173	177
Moisture Content, % by vol.	10.0	9.9	10.0
O2 at Sampling Location, %	16.2	16.1	16.5
Measured Particulate Emissions (2)			
lbs/hr	0.0064	0.0028	0.0050
lbs/MWH	0.00019	0.00008	0.00015
Average lbs/MWH		0.00014	

.0048 hr

1). See Appendix 3 for additional operating data.

Page 6
ATT. No. 2

CC. J. Cumbo
T. Nelson

BAGHOUSE DUST

GENERAL ENGINEERING LABORATORIES

Environmental Engineering and Analytical Services

Molly F. Greene
President

George C. Greene, P.E., Ph.D.
Vice President
SC Registration No. 9103

Laboratory Certifications	
FL	E87156/87294
NC	233
SC	10120
VA	00151
TN	02934
WI	999888779

CERTIFICATE OF ANALYSIS

Client: MacAlloy Corporation
P.O. Box 130
Charleston, South Carolina 29402
Contact: Mr. Tim Nelson

Date: 08/17/92

Released by:
QA/QC Officer

CC: MALY00191 Project Manager: Terri Fitzgerald Page No.: 1

Sample ID : Baghouse Dust
Lab ID : 9207610-02
Matrix : Misc.
Date Collected : 07/30/92
Date Received : 07/30/92
Priority : Routine
Collector : Client

Metals Analysis			
Aluminum	16500 ppm	Al_2O_3	3.12%
Calcium	3760 ppm	CaO	0.53%
Chromium	4450 ppm	Cr_2O_3	0.65%
Iron	14300 ppm	FeO	1.84%
Magnesium	106000 ppm	MgO	17.57%
Manganese	1730 ppm	MnO	0.22%
Lead	803 ppm	PbO	565 ppm
Silicon	193 ppm	SiO_2	303 ppm
General Chemistry			
Total Carbon	59500 ppm	5.95%	
Solids, Volatile	41800 ppm	4.18%	

The following preparation procedures were performed:
Acid Digestion Prep for Metals

4

Attachment 4

Particle-Size Distribution Study

5

Dr. Wojciech Z. Misiolek
Materials Engineering Consultant
17 Glen Drive
Troy, New York 12180

PHONE (518) 276-6099, (518) 276-5634, FAX (518) 276-8554

November 14, 1992

RECEIVED
NOV 16 1992

Guy D. Van Doren, P.E.
Vice President
Lan Associates Inc.
Environmental and Facilities Engineering
20 Cordova Street
St. Augustine, FL 32084-3619

Dear Mr. Van Doren,

Enclosed is the Progress Report I on **The Particle Size Distribution of the Fume Dust** together with the invoice for this project. After sorting out some technical difficulties we were able to perform these measurements for you.

In my personal opinion we need an additional scanning electron microscopy (SEM) analysis to be able to completely understand the fume dust morphology. I will contact you in a couple of days to discuss these eventual measurements with you.

If you have any questions related to the performed tests and their analysis do not hesitate to call me at (518) 276-6099. Please note change of my home address and phone number as indicated above.

Sincerely,

Wojciech Z. Misiolek, Sc.D.
Materials Engineering Consultant

WZM/consult/lan.2

INVOICE I

TO:
LAN Associates Inc.
Environmental and Facilities Engineering
20 Cordova Street
St. Augustine, FL 32084-3619

Attn: Guy D. Van Doren, Vice President

FROM:
Dr. W. Z. Misiolek
Materials Engineering Consultant
17 Glen Drive
Troy, NY 12180

DATE: November 14, 1992

EQUIPMENT FEE			
	Microtrac	12 x $15	$180.00
LABOR			
Nick Sopchak		9 x $20	$180.00
Wojciech Misiolek		4 x $100	$400.00
TOTAL			$760.00

Dr. Wojciech Z. Misiolek
Materials Engineering Consultant
17 Glen Drive
Troy, New York 12180

PHONE: 518/276-6099, 518/283-3806, FAX: 518/276-8554

PROGRESS REPORT I

THE PARTICLE SIZE DISTRIBUTION OF THE FUME DUST

prepared for

LAN Associates Inc.
Environmental and Facilities Engineering
20 Cordova Street
St. Augustine, FL 32084-3619

November 1992

Dr. Wojciech Z. Misiolek
Materials Engineering Consultant
17 Glen Drive
Troy, New York 12180

PHONE: 518/276-6099, 518/283-3806, FAX: 518/276-8554

PARTICLE SIZE DISTRIBUTION OF THE FUME DUST

Introduction

The particle size distribution is one of the measurements of the whole characterization package for the fume dust. The goal of this project was to measure and analyze particle size and its distribution in twelve provided fume dust samples. The overall objective is to understand formation of the dust particles and it eventual consolidation for the further processing.

Methodology

The laser scattering method was implemented for these measurements and the state-of-the art particle size analyzer, the Microtrak FRA, was used. The laser scattering method is the most common due to its high precision and high speed. However, the measured laser diffraction data are used for the calculation of particle size and its distribution based on an assumption of the particles spherical shape. It is the source of the eventual error, but the same assumption of particle spherical shape is made in all alternative methods except scanning electron microscopy.

First measurements obtained for the analyzed fume dust were quite inconsistent. Leeds & Northrup, equipment manufacturer, was consulted and they informed us that SiO_2 based powders are extremely difficult to disperse. Sodium metaphosphate was also suggested as a surfactant for these powders. It was decided to use recommended surfactant and to repeat all of the previously performed measurements.

Each sample was prepared in the form of suspended powder in water and then tested. To minimize an agglomeration, sodium metaphosphate surfactant was used, and all the samples were exposed to the ultrasound vibration for one minute prior testing. Samples prepared in this fashion were tested and three measurements were taken for each powder.

Results

The results for each measurement are presented in the form of table followed by the histogram plot; frequency v. particle size (based on a logarithmic scale). At the end the average values for the performed three tests on a given powder sample are provided in the same form of table and histogram plot. The data for all tested twelve samples are provided in an Appendix A. A summary table allows a direct comparison of most typical values like particle size for 50% frequency and average particle size.

TABLE I

Particle Size Summary Table

Sample No.	"50%" Particle Size (μm)	Average Particle Size (μm)	The same Sample Measurements
1	0.38	0.39	Inconsistent
2	0.50	0.52	Consistent
3	0.39	0.38	Inconsistent
4	0.40	0.40	Consistent
5	0.47	0.47	Consistent
6	0.48	0.50	Consistent
7	0.51	0.53	Consistent
8	0.47	0.48	Inconsistent
9	0.38	0.38	Consistent
10	0.39	0.41	Consistent
11	0.47	0.50	Consistent
13	0.52	0.55	Consistent

Discussion

The comparison of measurements indicated that they were quite consistent for each powder with the exception of samples number 1, number 3, and number 8, where one out of three test provided different results. The fact that particle size for 50% frequency is so close to average value is an indication of typical powder size distribution. However, more detailed analysis, especially using histogram plot, pointed out the additional peaks for larger particle diameter. These secondary peaks appears to be agglomerates or aggregates.

Agglomerate is defined as a collection of fine particles bonded together by secondary bonds, and appears as large particle. This kind of particle cluster can be usually relatively easy broken into individual particles during processing. The second type of large diameter particle cluster, which is build from the fine particles bonded together by the primary bonds is called aggregate. It is almost impossible to separate each individual particle from the aggregate during processing. This causes additional technological difficulties in terms of lower density, declined powder flow, and difficulties with powder compaction.

All tested powders have their average particle size in the 0.38 to 0.55 µm size range. There are relatively small differences, especially taking into account fact that all the powders exhibited the multi-modal size distribution. The major difficulty with this data is a fact that both 50% and average size values do not represent tested powders well. The majority of the powders is smaller that 50% size in each batch. It is necessary to perform an additional investigation in order to evaluate true particle size distribution.

It would be very beneficial for this project to exam and evaluate the nature of the particle collections, and the character of the present inter-particle bonds. The best method for this kind of analysis seems to be scanning electron microscopy (SEM). This technique provides sufficient information about particle size and shape, its surface texture, and kind of inter-particle bonding.

Summary and Recommendation

As indicated above all tested fume dust samples exhibited multi-modal distribution with average particle size between 0.38 and 0.55 µm. Due to this multi-modal character the whole particle size distribution is shifted toward the high end. To evaluate the particle size distribution of the fume dust in an explicit way, the precise characterization of large particles responsible for the secondary peeks is necessary. It is recommended to perform additional powder characterization analysis for particle size and shape using SEM technique.

Attachment 5

“Ferroalloy Production” (*Metallurgical Industry*)
EPA AP-42 Manual (10/86)

United States
Environmental Protection
Agency

Office of Air Quality
Planning and Standards
Research Triangle Park NC 27711

AP-42
Fifth Edition
January 1995

Air

EPA

PB95-196028

PART1 OF 3

COMPILATION OF AIR POLLUTANT EMISSION FACTORS

VOLUME I: STATIONARY POINT AND AREA SOURCES

FIFTH EDITION

12.4 Ferroalloy Production

12.4.1 General

Ferroalloy is an alloy of iron with some element other than carbon. Ferroalloy is used to physically introduce or "carry" that element into molten metal, usually during steel manufacture. In practice, the term ferroalloy is used to include any alloys that introduce reactive elements or alloy systems, such as nickel and cobalt-based aluminum systems. Silicon metal is consumed in the aluminum industry as an alloying agent and in the chemical industry as a raw material in silicon-based chemical manufacturing.

The ferroalloy industry is associated with the iron and steel industries, its largest customers. Ferroalloys impart distinctive qualities to steel and cast iron and serve important functions during iron and steel production cycles. The principal ferroalloys are those of chromium, manganese, and silicon. Chromium provides corrosion resistance to stainless steels. Manganese is essential to counteract the harmful effects of sulfur in the production of virtually all steels and cast iron. Silicon is used primarily for deoxidation in steel and as an alloying agent in cast iron. Boron, cobalt, columbium, copper, molybdenum, nickel, phosphorus, titanium, tungsten, vanadium, zirconium, and the rare earths impart specific characteristics and are usually added as ferroalloys.

United States ferroalloy production in 1989 was approximately 894,000 megagrams (Mg) (985,000 tons), substantially less than shipments in 1975 of approximately 1,603,000 megagrams (1,770,000 tons). In 1989, ferroalloys were produced in the U. S. by 28 companies, although 5 of those produced only ferrophosphorous as a byproduct of elemental phosphorous production.

12.4.2 Process Description

A typical ferroalloy plant is illustrated in Figure 12.4-1. A variety of furnace types, including submerged electric arc furnaces, exothermic (metallothermic) reaction furnaces, and electrolytic cells can be used to produce ferroalloys. Furnace descriptions and their ferroalloy products are given in Table 12.4-1.

12.4.2.1 Submerged Electric Arc Process -

In most cases, the submerged electric arc furnace produces the desired product directly. It may produce an intermediate product that is subsequently used in additional processing methods. The submerged arc process is a reduction smelting operation. The reactants consist of metallic ores (ferrous oxides, silicon oxides, manganese oxides, chrome oxides, etc.) and a carbon-source reducing agent, usually in the form of coke, charcoal, high- and low-volatility coal, or wood chips. Limestone may also be added as a flux material. Raw materials are crushed, sized, and, in some cases, dried, and then conveyed to a mix house for weighing and blending. Conveyors, buckets, skip hoists, or cars transport the processed material to hoppers above the furnace. The mix is then gravity-fed through a feed chute either continuously or intermittently, as needed. At high temperatures in the reaction zone, the carbon source reacts with metal oxides to form carbon monoxide and to reduce the ores to base metal. A typical reaction producing ferrosilicon is shown below:

$$Fe_2O_3 + 2SiO_2 + 7C \rightarrow 2FeSi + 7\ CO \qquad (1)$$

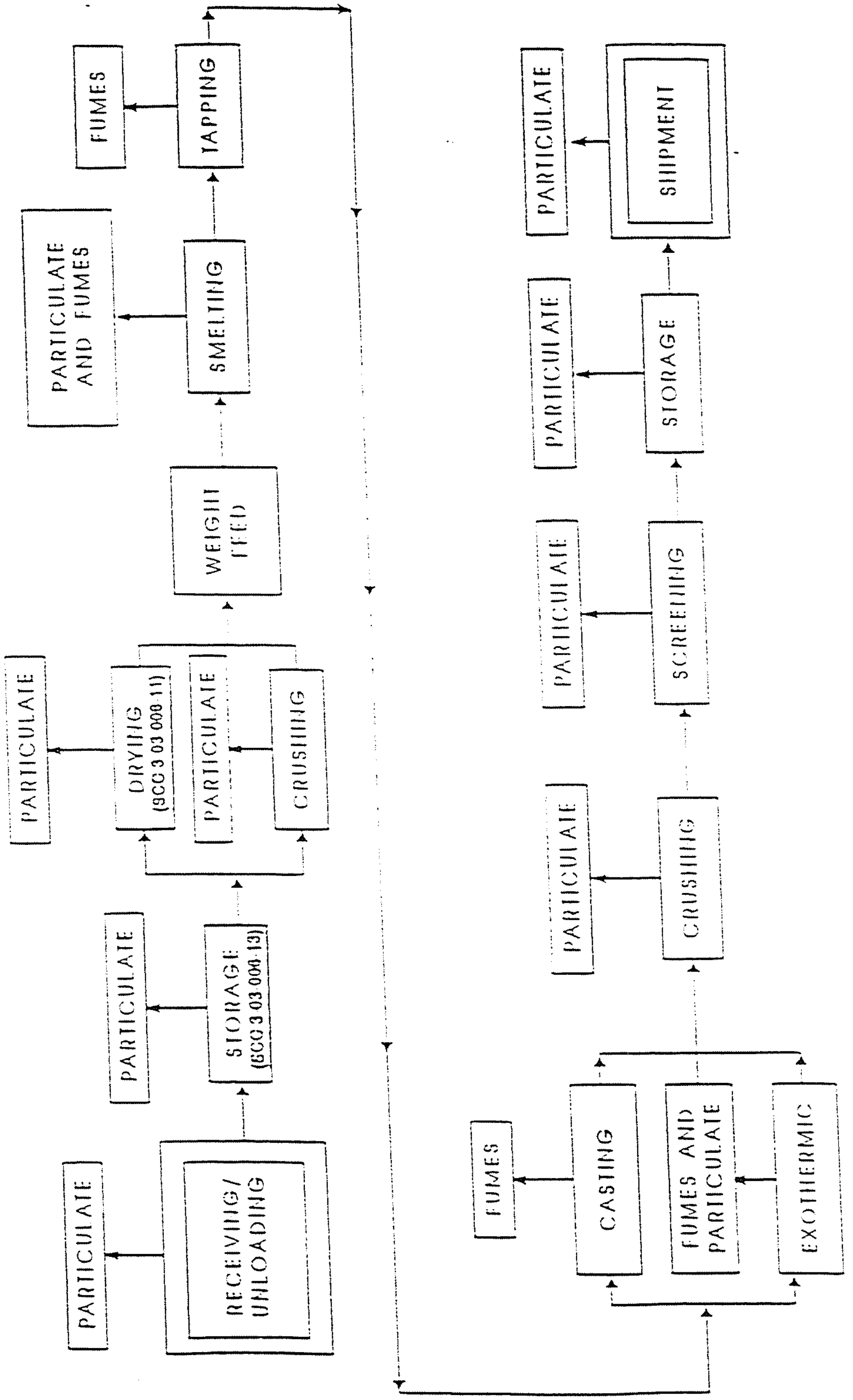

Figure 12.4-1. Typical ferroalloy production process. (Source Cla [illegible]

Table 12.4-1. FERROALLOY PROCESSES AND RESPECTIVE PRODUCT GROUPS

Process	Product
Submerged arc furnace[a]	Silvery iron (15-22% Si) Ferrosilicon (50% Si) Ferrosilicon (65-75% Si) Silicon metal Silicon/manganese/zirconium (SMZ) High carbon (HC) ferromanganese Siliconmanganese HC ferrochrome Ferrochrome/silicon FeSi (90% Si)
Exothermic[b]	
Silicon reduction	Low carbon (LC) ferrochrome, LC ferromanganese, medium carbon (MC) ferromanganese
Aluminum Reduction	Chromium metal, ferrotitanium, ferrocolumbium, ferovanadium
Mixed aluminothermal/silicothermal	Ferromolybdenum, ferrotungsten
Electrolytic[c]	Chromium metal, manganese metal
Vacuum furnace[d]	LC ferrochrome
Induction furnace[e]	Ferrotitanium

[a] Process by which metal is smelted in a refractory-lined cup-shaped steel shell by submerged graphite electrodes.

[b] Process by which molten charge material is reduced, in exothermic reaction, by addition of silicon, aluminum, or a combination of the 2.

[c] Process by which simple ions of a metal, usually chromium or manganese in an electrolyte, are plated on cathodes by direct low-voltage current.

[d] Process by which carbon is removed from solid-state high-carbon ferrochrome within vacuum furnaces maintained at temperatures near melting point of alloy.

[e] Process that converts electrical energy into heat, without electrodes, to melt metal charges in a cup or drum-shaped vessel.

Smelting in an electric arc furnace is accomplished by conversion of electrical energy to heat. An alternating current applied to the electrodes causes current to flow through the charge between the electrode tips. This provides a reaction zone at temperatures up to 2000°C (3632°F). The tip of each electrode changes polarity continuously as the alternating current flows between the tips. To maintain a uniform electric load, electrode depth is continuously varied automatically by mechanical or hydraulic means.

A typical submerged electric arc furnace design is depicted in Figure 12.4-2. The lower p of the submerged electric arc furnace is composed of a cylindrical steel shell with a flat bottom or hearth. The interior of the shell is lined with 2 or more layers of carbon blocks. The furnace shell may be water-cooled to protect it from the heat of the process. A water-cooled cover and fume collection hood are mounted over the furnace shell. Normally, 3 carbon electrodes arranged in a triangular formation extend through the cover and into the furnace shell opening. Prebaked or self-baking (Soderberg) electrodes ranging from 76 to over 100 cm (30 to over 40 inches) in diameter a typically used. Raw materials are sometimes charged to the furnace through feed chutes from above the furnace. The surface of the furnace charge, which contains both molten material and unconverted charge during operation, is typically maintained near the top of the furnace shell. The lower ends of the electrodes are maintained at about 0.9 to 1.5 meters (3 to 5 feet) below the charge surface. Three-phase electric current arcs from electrode to electrode, passing through the charge material. The charge material melts and reacts to form the desired product as the electric energy is converted into heat. The carbonaceous material in the furnace charge reacts with oxygen in the metal oxides of the charge and reduces them to base metals. The reactions produce large quantities of carbon monoxide (CO) that passes upward through the furnace charge. The molten metal and slag are removed (tapped) through 1 or more tap holes extending through the furnace shell at the hearth level. Feed materials may be charged continuously or intermittently. Power is applied continuously. Tapping can be intermittent or continuous based on production rate of the furnace.

Submerged electric arc furnaces are of 2 basic types, open and covered. Most of the submerged electric arc furnaces in the U. S. are open furnaces. Open furnaces have a fume collection hood at least 1 meter (3.3 feet) above the top of the furnace shell. Moveable panels or screens are sometimes used to reduce the open area between the furnace and hood, and to improve emissions capture efficiency. Carbon monoxide rising through the furnace charge burns in the area between the charge surface and the capture hood. This substantially increases the volume of gas the containment system must handle. Additionally, the vigorous open combustion process entrains finer material in the charge. Fabric filters are typically used to control emissions from open furnaces.

Covered furnaces may have a water-cooled steel cover that fits closely to the furnace shell. The objective of covered furnaces is to reduce air infiltration into the furnace gases, which reduces combustion of that gas. This reduces the volume of gas requiring collection and treatment. The cover has holes for the charge and electrodes to pass through. Covered furnaces that partially close these hood openings with charge material are referred to as "mix-sealed" or "semi-enclosed furnaces". Although these covered furnaces significantly reduce air infiltration, some combustion still occurs under the furnace cover. Covered furnaces that have mechanical seals around the electrodes and sealing compounds around the outer edges are referred to as "sealed" or "totally closed". These furnaces have little, if any, air infiltration and undercover combustion. Water leaks from the cover into the furnace must be minimized as this leads to excessive gas production and unstable furnace operation. Products prone to highly variable releases of process gases are typically not made in covered furnaces for safety reasons. As the degree of enclosure increases, less gas is produced for capture by the hood system and the concentration of carbon monoxide in the furnace gas increases. Wet scrubbers are used to control emissions from covered furnaces. The scrubbed, high carbon monoxide content gas may be used within the plant or flared.

The molten alloy and slag that accumulate on the furnace hearth are removed at 1 to 5-hour intervals through the tap hole. Tapping typically lasts 10 to 15 minutes. Tap holes are opened with pellet shot from a gun, by drilling, or by oxygen lancing. The molten metal and slag flow from the tap hole into a carbon-lined trough, then into a carbon-lined runner that directs the metal and slag into a reaction ladle, ingot molds, or chills. (Chills are low, flat iron or steel pans that provide rapid

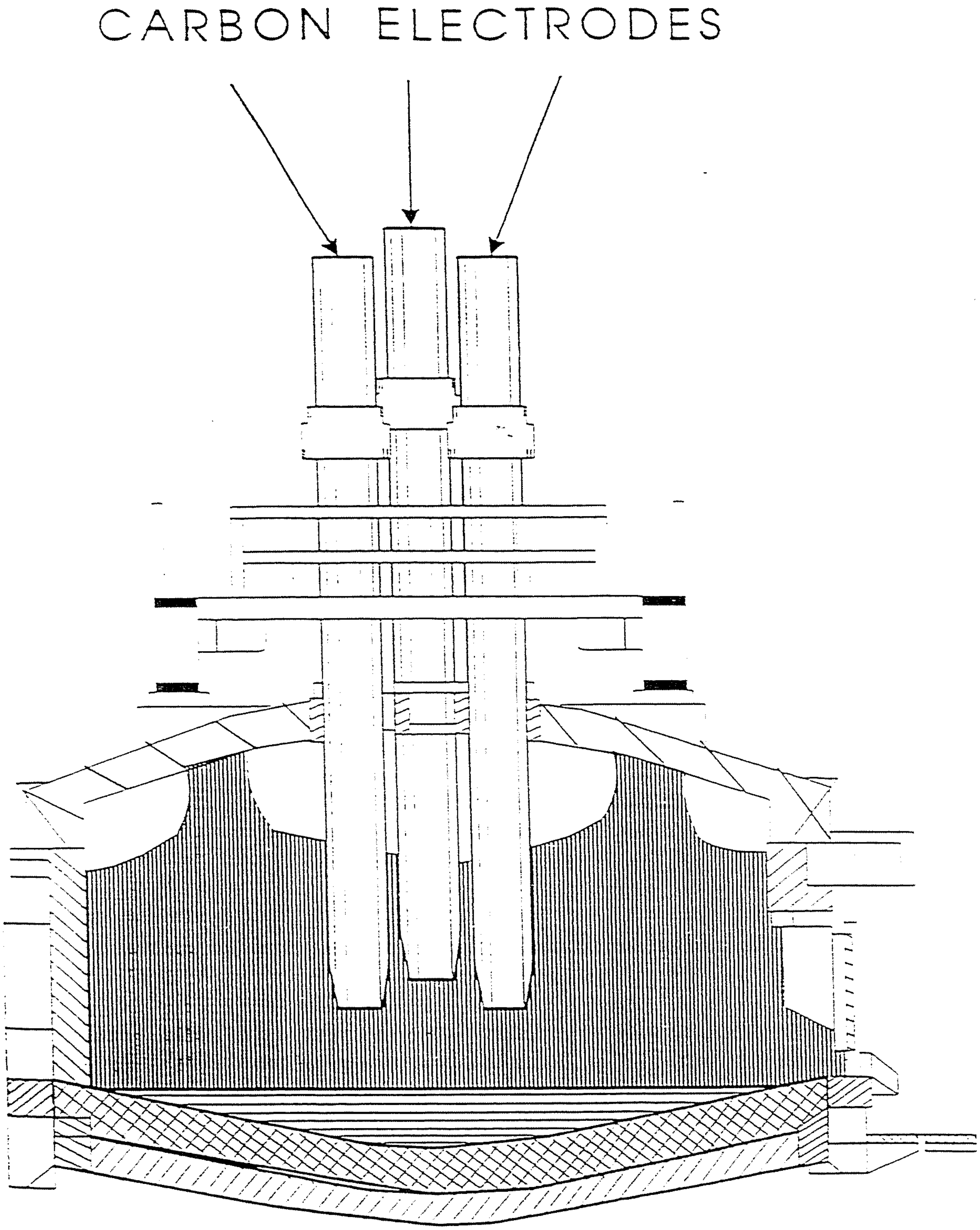

Figure 12.4-2. Typical submerged arc furnace design.

cooling of the molten metal.) After tapping is completed, the furnace is resealed by inserting a carbon paste plug into the tap hole.

Chemistry adjustments may be necessary after furnace smelting to achieve a specified product. Ladle treatment reactions are batch processes and may include metal and alloy additions.

During tapping, and/or in the reaction ladle, slag is skimmed from the surface of the molten metal. It can be disposed of in landfills, sold as road ballast, or used as a raw material in a furnace or reaction ladle to produce a chemically related ferroalloy product.

After cooling and solidifying, the large ferroalloy castings may be broken with drop weights or hammers. The broken ferroalloy pieces are then crushed, screened (sized), and stored in bins until shipment. In some instances, the alloys are stored in lump form in inventories prior to sizing for shipping.

12.4.2.2 Exothermic (Metallothermic) Process -

The exothermic process is generally used to produce high-grade alloys with low-carbon content. The intermediate molten alloy used in the process may come directly from a submerged electric arc furnace or from another type of heating device. Silicon or aluminum combines with oxygen in the molten alloy, resulting in a sharp temperature rise and strong agitation of the molten bath. Low- and medium-carbon content ferrochromium (FeCr) and ferromanganese (FeMn) are produced by silicon reduction. Aluminum reduction is used to produce chromium metal, ferrotitanium, ferrovanadium, and ferrocolumbium. Mixed alumino/silico thermal processing is used for producing ferromolybdenum and ferrotungsten. Although aluminum is more expensive than carbon or silicon, the products are purer. Low-carbon (LC) ferrochromium is typically produced by fusing chromium ore and lime in a furnace. A specified amount is then placed in a ladle (ladle No. 1). A known amount of an intermediate grade ferrochromesilicon is then added to the ladle. The reaction is extremely exothermic and liberates chromium from its ore, producing LC ferrochromium and a calcium silicate slag. This slag, which still contains recoverable chromium oxide, is reacted in a second ladle (ladle No. 2) with molten high-carbon ferrochromesilicon to produce the intermediate-grade ferrochromesilicon. Exothermic processes are generally carried out in open vessels and may have emissions similar to the submerged arc process for short periods while the reduction is occurring.

12.4.2.3 Electrolytic Processes -

Electrolytic processes are used to produce high-purity manganese and chromium. As of 1989 there were 2 ferroalloy facilities using electrolytic processes.

Manganese may be produced by the electrolysis of an electrolyte extracted from manganese ore or manganese-bearing ferroalloy slag. Manganese ores contain close to 50 percent manganese; furnace slag normally contains about 10 percent manganese. The process has 5 steps: (1) roasting the ore to convert it to manganese oxide (MnO), (2) leaching the roasted ore with sulfuric acid (H_2SO_4) to solubilize manganese, (3) neutralization and filtration to remove iron and aluminum hydroxides, (4) purifying the leach liquor by treatment with sulfide and filtration to remove a wide variety of metals, and (5) electrolysis.

Electrolytic chromium is generally produced from high-carbon ferrochromium. A large volume of hydrogen gas is produced by dissolving the alloy in sulfuric acid. The leachate is treated with ammonium sulfate and conditioned to remove ferrous ammonium sulfate and produce a chrome-alum for feed to the electrolysis cells. The electrolysis cells are well ventilated to reduce ambient hydrogen and hexavalent chromium concentrations in the cell rooms.

12.4.3 Emissions And Controls

Particulate is generated from several activities during ferroalloy production, including raw material handling, smelting, tapping, and product handling. Organic materials are generated almost exclusively from the smelting operation. The furnaces are the largest potential sources of particulate and organic emissions. The emission factors are given in Tables 12.4-2 and 12.4-3. Size-specific emission factors for submerged arc ferroalloy furnaces are given in Tables 12.4-4 and 12.4-5.

Particulate emissions from electric arc furnaces in the form of fumes account for an estimated 94 percent of the total particulate emissions in the ferroalloy industry. Large amounts of carbon monoxide and organic materials also are emitted by submerged electric arc furnaces. Carbon monoxide is formed as a byproduct of the chemical reaction between oxygen in the metal oxides of the charge and carbon contained in the reducing agent (coke, coal, etc.). Reduction gases containing organic compounds and carbon monoxide continuously rise from the high-temperature reaction zone, entraining fine particles and fume precursors. The mass weight of carbon monoxide produced sometimes exceeds that of the metallic product. The heat-induced fume consists of oxides of the products being produced and carbon from the reducing agent. The fume is enriched by silicon dioxide, calcium oxide, and magnesium oxide, if present in the charge.

In an open electric arc furnace, virtually all carbon monoxide and much of the organic matter burns with induced air at the furnace top. The remaining fume, captured by hooding about 1 meter above the furnace, is directed to a gas cleaning device. Fabric filters are used to control emissions from 85 percent of the open furnaces in the U. S. Scrubbers are used on 13 percent of the furnaces, and electrostatic precipitators on 2 percent.

Two emission capture systems, not usually connected to the same gas cleaning device, are necessary for covered furnaces. A primary capture system withdraws gases from beneath the furnace cover. A secondary system captures fumes released around the electrode seals and during tapping. Scrubbers are used almost exclusively to control exhaust gases from sealed furnaces. The scrubbers capture a substantial percentage of the organic emissions, which are much greater for covered furnaces than open furnaces. The gas from sealed and mix-sealed furnaces is usually flared at the exhaust of the scrubber. The carbon monoxide-rich gas is sometimes used as a fuel in kilns and sintering machines. The efficiency of flares for the control of carbon monoxide and the reduction of VOCs has been estimated to be greater than 98 percent. A gas heating reduction of organic and carbon monoxide emissions is 98 percent efficient.

Tapping operations also generate fumes. Tapping is intermittent and is usually conducted during 10 to 20 percent of the furnace operating time. Some fumes originate from the carbon lip liner, but most are a result of induced heat transfer from the molten metal or slag as it contacts the runners, ladles, casting beds, and ambient air. Some plants capture these emissions to varying degrees with a main canopy hood. Other plants employ separate tapping hoods ducted to either the furnace emission control device or a separate control device. Emission factors for tapping emissions are unavailable due to lack of data.

After furnace tapping is completed, a reaction ladle may be used to adjust the metallurgy by chlorination, oxidation, gas mixing, and slag metal reactions. Ladle reactions are an intermittent process, and emissions have not been quantified. Reaction ladle emissions are often captured by the tapping emissions control system.

Table 12.4-2 (Metric Units). EMISSION FACTORS FOR PARTICULATE FROM SUBMERGED ARC FERROALLOY FURNACES[a]

Product[b]	Furnace Type	Particulate Emission Factors Uncontrolled[c]	EMISSION FACTOR RATING	Control Device[d]	Particulate Emission Factors Controlled[e]	EMISSION FACTOR RATING
FeSi (50%) (SCC 3-03-006-01)	Open[e,f,g]	35	B	Baghouse[e,f]	0.9	B
	Covered[h]	46	E	Scrubber[h,j]		
				High energy	0.24	E
				Low energy	4.5	E
FeSi (75%) (SCC 3-03-006-02)	Open[k]	158	E	Scrubber[h,j]		
				Low energy	4.0	E
	Covered[h,j]	103	E	ND	ND	NA
FeSi (90%) (SCC 3-03-006-03)	Open[m]	282	E	ND	ND	NA
Si metal (98%) (SCC 3-03-006-04)	Open[n,p]	436	B	Baghouse[n,p]	16	B
FeMn (80%) (SCC 3-03-006-06)	Open[q,r]	14	B	Baghouse[q,r]	0.24	B
				Scrubber[h,s]		
				High energy	0.8	E
FeMn (1% Si) (SCC 3-03-007-01)	Covered[h,t]	6	E	Scrubber	0.25	C
				High energy[h,s,w]		
	Sealed[u,v]	37	E	ND	ND	NA
FeCr (high carbon) (SCC 3-03-006-07)	Open[x,y]	78	C	ESP[x,y]	1.2	C
SiMn (SCC 3-03-006-05)	Open[z,aa]	96	C	Scrubber[aa,bb]	2.1	C
	Sealed	—	—	Scrubber[v,w]		
				High energy	0.15	C

[a] Emission factors are expressed as kg of pollutant/Mg alloy produced. Factors are for main furnace dust collection system before and after control device. Where other emissions, such as leaks or tapping, are included or quantified separately, such is noted. Particulate sources not included: raw material handling, storage, and preparation; and product crushing, screening, handling, and packaging. SCC = Source Classification Code. ND = no data. NA = not applicable.

[b] **Percentages are of the main alloying agent in product.**

Table 12.4-2 (cont.).

[c] In most source testing, fugitive emissions are not measured or collected. Where tapping emissions are controlled by primary system, their contribution to total emissions could not be determined. Fugitive emissions may vary greatly among sources, with furnace and collection system design and operating practices.

[d] Low-energy scrubbers are those with $\Delta P < 20$ inches of H_2O; high-energy with $\Delta P > 20$ inches of H_2O.

[e] Includes fumes captured by tapping hood (efficiency estimated at near 100%).

[f] References 4,10,21.

[g] Factor is average of 3 sources, fugitive emissions not included. Fugitive emissions at 1 source measured an additional 10.5 kg/Mg alloy, or 2.7 kg/MW-hr.

[h] References 4,10.

[j] Does not include emissions from tapping or mix seal leaks.

[k] References 25-26.

[m] Reference 23.

[n] Estimated 60% of tapping emissions captured by control system (escaped fugitive emissions not included in factor).

[p] References 10,13.

[q] Estimated 50% of tapping emissions captured by control system (escaped fugitive emissions not included in factor).

[r] References 4,10,12.

[s] Includes fumes only from primary control system.

[t] Includes tapping fumes and mix seal leak fugitive emissions. Fugitive emissions measured at 33% of total uncontrollable emissions.

[u] Assumes tapping fumes not included in emission factor.

[v] Reference 14.

[w] Does not include tapping or fugitive emissions.

[x] Tapping emissions included.

[y] References 2,15-17.

[z] Factor is average of 2 test series. Tests at 1 source included fugitive emissions (3.4% of total uncontrolled emissions). Second test insufficient to determine if fugitive emissions were included in total.

[aa] References 2,18-19.

[bb] Factors developed from 2 scrubber controlled sources, 1 operated at $\Delta P = 47\text{-}57$ inches of H_2O, the other at unspecified ΔP. Uncontrolled tapping operations emissions are 2.1 kg/Mg alloy.

Table 12.4-3 (English Units). EMISSION FACTORS FOR PARTICULATE FROM SUBMERGED ARC FERROALLOY FURNACES[a]

Product[b]	Furnace Type	Particulate Emission factors Uncontrolled[c]	EMISSION FACTOR RATING	Control Device[d]	Particulate Emission factors Controlled[c]	EMISSION FACTOR RATING
FeSi (50%) (SCC 3-03-006-01)	Open[e,f,g]	70	B	Baghouse[e,f]	1.8	B
	Covered[h]	92	E	Scrubber[h,j]		
				High energy	0.48	E
				Low energy	9.0	E
FeSi (75%) (SCC 3-03-006-02)	Open[k]	316	E	Scrubber[h,j]		
				Low energy	8.0	E
	Covered[h,j]	206	E	ND	ND	NA
FeSi (90%) (SCC 3-03-006-03)	Open[m]	564	E	ND	ND	NA
Si metal (98%) (SCC 3-03-006-04)	Open[n,p]	872	B	Baghouse[n,p]	32	B
FeMn (80%) (SCC 3-03-006-06)	Open[q,r]	28	B	Baghouse[q,r]	0.48	B
				Scrubber[h,s]		
				High energy	1.6	E
FeMn (1% Si) (SCC 3-03-007-01)	Covered[h,t]	12	E	Scrubber		
				High energy[h,s,w]	0.5	C
	Sealed[u,v]	74	E	ND	ND	NA
FeCr (high carbon) (SCC 3-03-006-07)	Open[x,y]	157	C	ESP[x,y]	2.3	C
SiMn (SCC 3-03-006-05)	Open[z,aa]	192	C	Scrubber[aa,bb]	4.2	C
	Sealed	—	—	Scrubber[v,w]		
				High energy	0.30	C

[a] Emission factors expressed as lb of pollutant/ton of Alloy produced. Factors are for main furnace dust collection system before and after control device. Where other emissions, such as leaks or tapping, are included or quantified separately, such is noted. Particulate sources not included: raw material handling, storage, and preparation; and product crushing, screening, handling, and packaging. SCC = Source Classification Code. ND = no data. NA = not applicable.

[b] Percentages are of the main alloying agent in product.

Table 12.4-3 (cont.).

[c] In most source testing, fugitive emissions are not measured or collected. Where tapping emissions are controlled by primary system, their contribution to total emissions could not be determined. Fugitive emissions may vary greatly among sources, with furnace and collection system design and operating practices.

[d] Low-energy scrubbers are those with $\Delta P < 20$ inches of H_2O; high-energy with $\Delta P > 20$ inches of H_2O.

[e] Includes fumes captured by tapping hood (efficiency estimated at near 100%).

[f] References 4,10,21.

[g] Factor is average of 3 sources, fugitive emissions not included. Fugitive emissions at 1 source measured an additional 21 lb/ton alloy, or 5.9 lb/MW-hr.

[h] References 4,10.

[j] Does not include emissions from tapping or mix seal leaks.

[k] References 25-26.

[m] Reference 23.

[n] Estimated 60% of tapping emissions captured by control system (escaped fugitive emissions not included in factor).

[p] References 10,13.

[q] Estimated 50% of tapping emissions captured by control system (escaped fugitive emissions not included in factor).

[r] References 4,10,12.

[s] Includes fumes only from primary control system.

[t] Includes tapping fumes and mix seal leak fugitive emissions. Fugitive emissions measured at 33% of total uncontrollable emissions.

[u] Assumes tapping fumes not included in emission factor.

[v] Reference 14.

[w] Does not include tapping or fugitive emissions.

[x] Tapping emissions included.

[y] References 2,15-17.

[z] Factor is average of 2 test series. Tests at 1 source included fugitive emissions (3.4% of total uncontrolled emissions). Second test insufficient to determine if fugitive emissions were included in total.

[aa] References 2,18-19.

[bb] Factors developed from 2 scrubber controlled sources, 1 operated at $\Delta P = 47\text{-}57$ inches of H_2O, the other at unspecified ΔP. Uncontrolled tapping operations emissions are 4.2 lb/ton alloy.

Table 12.4-4 (Metric Units). SIZE-SPECIFIC EMISSION FACTORS FOR SUBMERGED ARC FERROALLOY FURNACES

Product	Control Device	Particle Size[a] (μm)	Cumulative Mass % ≤ Stated Size	Cumulative Mass Emission Factor (kg/Mg alloy)	EMISSION FACTOR RATING
50% FeSi Open furnace (SCC 3-03-006-01)	None[b,c]	0.63	45	16	B
		1.00	50	18	
		1.25	53	19	
		2.50	57	20	
		6.00	61	21	
		10.00	63	22	
		15.00	66	23	
		20.00	69	24	
		—[d]	100	35	
	Baghouse	0.63	31	0.28	B
		1.00	39	0.35	
		1.25	44	0.40	
		2.50	54	0.49	
		6.00	63	0.57	
		10.00	72	0.65	
		15.00	80	0.72	
		20.00	85	0.77	
			100	0.90	
80% FeMn Open furnace (SCC 3-03-006-06)	None[e,f]	0.63	30	4	B
		1.00	46	7	
		1.25	52	8	
		2.50	62	9	
		6.00	72	10	
		10.00	86	12	
		15.00	96	13	
		20.00	97	14	
		—[d]	100	14	
	Baghouse[e]	0.63	20	0.048	B
		1.00	30	0.070	
		1.25	35	0.085	
		2.50	49	0.120	
		6.00	67	0.160	
		10.00	83	0.200	
		15.00	92	0.220	
		20.00	97	0.235	
		—[d]	100	0.240	

Table 12.4-4 (cont.).

Product	Control Device	Particle Size[a] (µm)	Cumulative Mass % ≤ Stated Size	Cumulative Mass Emission Factor (kg/Mg alloy)	EMISSION FACTOR RATING
Si Metal[g]					
Open furnace (SCC 3-03-006-04)	None[h]	0.63	57	249	B
		1.00	67	292	
		1.25	70	305	
		2.50	75	327	
		6.00	80	349	
		10.00	86	375	
		15.00	91	397	
		20.00	95	414	
		—[d]	100	436	
	Baghouse	1.00	49	7.8	
		1.25	53	8.5	
		2.50	64	10.2	
		6.00	76	12.2	
		10.00	87	13.9	
		15.00	96	15.4	
		20.00	99	15.8	
			100	16.0	
FeCr (HC)					
Open furnace (SCC 3-03-006-07)	None[b,j]	0.5	19	15	C
		1.0	36	28	
		2.0	60	47	
		2.5	63[k]	49	
		4.0	76	59	
		6.0	88[k]	67	
		10.0	91	71	
		—[d]	100	78	
	ESP	0.5	33	0.40	C
		1.0	47	0.56	
		2.0	67	0.80	
		2.5	80	0.96	
		4.0	86	1.03	
		6.0	90	1.08	
		10.0	100	1.2	
		—[d]			

Table 12.4-4 (cont.).

Product	Control Device	Particle Size[a] (µm)	Cumulative Mass % ≤ Stated Size	Cumulative Mass Emission Factor (kg/Mg alloy)	EMISSI FACTO RATIN
SiMn					
Open furnace (SCC 3-03-006-05)	None[b,m]	0.5	28	27	C
		1.0	44	42	
		2.0	60	58	
		2.5	65	62	
		4.0	76	73	
		6.0	85	82	
		10.0	96[k]	92[k]	
		—[d]	100	96	
	Scrubber[m,n]	0.5	56	1.18	C
		1.0	80	1.68	
		2.0	96	2.02	
		2.5	99	2.08	
		4.0	99.5	2.09	
		6.0	99.9[k]	2.10[k]	
		10.0	100	2.1	

[a] Aerodynamic diameter, based on Task Group On Lung Dynamics definition. Particle density = 1 g/cm^3.

[b] Includes tapping emissions.

[c] References 4,10,21.

[d] Total particulate, based on Method 5 total catch (see Tables 12.4-2 and 12.4-3).

[e] Includes tapping fumes (estimated capture efficiency 50%).

[f] References 4,10,12.

[g] References 10,13.

[h] Includes tapping fumes (estimated capture efficiency 60%).

[j] References 1,15-17.

[k] Interpolated data.

[m] References 2,18-19.

[n] Primary emission control system only, without tapping emissions.

Table 12.4-5 (English Units). SIZE-SPECIFIC EMISSION FACTORS FOR SUBMERGED ARC FERROALLOY FURNACES

Product	Control Device	Particle Size[a] (µm)	Cumulative Mass % ≤ Stated Size	Cumulative Mass Emission Factor (lb/ton alloy)	EMISSION FACTOR RATING
50% FeSi Open furnace (SCC 3-03-006-01)	None[b,c]	0.63	45	32	B
		1.00	50	35	
		1.25	53	37	
		2.50	57	40	
		6.00	61	43	
		10.00	63	44	
		15.00	66	46	
		20.00	69	48	
		—[d]	100	70	
	Baghouse	0.63	31	0.56	B
		1.00	39	0.70	
		1.25	44	0.80	
		2.50	54	1.0	
		6.00	63	1.1	
		10.00	72	1.3	
		15.00	80	1.4	
		20.00	85	1.5	
			100	1.8	
80% FeMn Open furnace (SCC 3-03-006-05)	None[e,f]	0.63	30	8	B
		1.00	46	13	
		1.25	52	15	
		2.50	62	17	
		6.00	72	20	
		10.00	86	24	
		15.00	96	26	
		20.00	97	27	
		—[d]	100	28	
	Baghouse[e]	0.63	20	0.10	B
		1.00	30	0.14	
		1.25	35	0.17	
		2.50	49	0.24	
		6.00	67	0.32	
		10.00	83	0.40	
		15.00	92	0.44	
		20.00	97	0.47	
		—[d]	100	0.48	

Table 12.4-5 (cont.).

Product	Control Device	Particle Size[a] (µm)	Cumulative Mass % ≤ Stated Size	Cumulative Mass Emission Factor (lb/ton alloy)	EMISSIO FACTO RATING
Si Metal[g] Open Furnace (SCC 3-03-006-04)	None[h]	0.63	57	497	B
		1.00	67	584	
		1.25	70	610	
		2.50	75	654	
		6.00	80	698	
		10.00	86	750	
		15.00	91	794	
		20.00	95	828	
		—[d]	100	872	
	Baghouse	1.00	49	15.7	B
		1.25	53	17.0	
		2.50	64	20.5	
		6.00	76	24.3	
		10.00	87	28.0	
		15.00	96	31.0	
		20.00	99	31.7	
			100	32.0	
FeCr (HC) Open furnace (SCC 3-03-006-07)	None[b,j]	0.5	19	30	C
		1.0	36	57	
		2.0	60	94	
		2.5	63[k]	99	
		4.0	76	119	
		6.0	88[k]	138	
		10.0	91	143	
		—[d]	100	157	
	ESP	0.5	33	0.76	C
		1.0	47	1.08	
		2.0	67	1.54	
		2.5	80	1.84	
		4.0	86	1.98	
		6.0	90	2.07	
		10.0	100	2.3	
		—[d]			

Table 12.4-5 (cont.).

Product	Control Device	Particle Size[a] (μm)	Cumulative Mass % ≤ Stated Size	Cumulative Mass Emission Factor (lb/ton alloy)	EMISSION FACTOR RATING
SiMn Open furnace (SCC 3-05-006-05)	None[b,m]	0.5	28	54	C
		1.0	44	84	
		2.0	60	115	
		2.5	65	125	
		4.0	76	146	
		6.0	85	163	
		10.0	96[k]	177[k]	
		—[d]	100	192	
	Scrubber[m,n]	0.5	56	2.36	C
		1.0	80	3.34	
		2.0	96	4.03	
		2.5	99	4.16	
		4.0	99.5	4.18	
		6.0	99.9[k]	4.20[k]	
		10.0	100	4.3	

[a] Aerodynamic diameter, based on Task Group On Lung Dynamics definition. Particle density = 1 g/cm^3.

[b] Includes tapping emissions.

[c] References 4,10,21.

[d] Total particulate, based on Method 5 total catch (see Tables 12.4-2 and 12.4-3).

[e] Includes tapping fumes (estimated capture efficiency 50%).

[f] References 4,10,12.

[g] References 10,13.

[h] Includes tapping fumes (estimated capture efficiency 60%).

[j] References 1,15-17.

[k] Interpolated data.

[m] References 2,18-19.

[n] Primary emission control system only, without tapping emissions.

Available data are insufficient to provide emission factors for raw material handling, pretreatment, and product handling. Dust particulate is emitted from raw material handling, storage, and preparation activities (see Figure 12.4-1). These activities include unloading raw materials from delivery vehicles (ship, railway car, or truck), storing raw materials in piles, loading raw materials from storage piles into trucks or gondola cars, and crushing and screening raw materials. Raw materials may be dried before charging in rotary or other types of dryers, and these dryers can generate significant particulate emissions. Dust may also be generated by heavy vehicles used for loading, unloading, and transferring material. Crushing, screening, and storage of the ferroalloy product emit particulate matter in the form of dust. The properties of particulate matter emitted as dust are similar to the natural properties of the ores or alloys from which they originated, ranging in size from 3 to 100 micrometers (μm).

Approximately half of all ferroalloy facilities have some type of control for dust emissions. Dust generated from raw material storage may be controlled in several ways, including sheltering storage piles from the wind with block walls, snow fences, or plastic covers. Occasionally, piles [illegible] sprayed with water to prevent airborne dust. Emissions generated by heavy vehicle traffic may be reduced by using a wetting agent or paving the plant yard. Moisture in the raw materials, which [illegible] be as high as 20 percent, helps to limit dust emissions from raw material unloading and loading. Dust generated by crushing, sizing, drying, or other pretreatment activities may be controlled by [illegible] collection equipment such as scrubbers, cyclones, or fabric filters. Ferroalloy product crushing and sizing usually require a fabric filter. The raw material emission collection equipment may be connected to the furnace emission control system. For fugitive emissions from open sources, see Section 13.2 of this document.

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9

Attachment 6

"Rocks and Minerals" Chapter 3: *Earth*
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EARTH

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NATIONAL ACADEMY OF SCIENCES

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3

Rocks and Minerals

Rocks and the minerals that make them up are the tangible record of geologic processes. The minerals of the Earth are understood in terms of their molecular architecture—the way their atoms are arranged in crystal structures. The kinds of atoms and their chemical bonding determine not only the crystal structures but the chemical and physical properties of minerals, all of which are used for their identification. Rocks are divided into the three major groups, igneous, metamorphic, and sedimentary, on the basis of origin. They are further subdivided within each group according to mineral composition and texture, which provide the data that allow us to interpret details of their origin.

Picking up pretty stones and showing or wearing them must go far back into human prehistory. The earliest records of practical use of stones, though, are of arrowheads and spear points made of flint (a sedimentary rock) or obsidian (volcanic glass), both of which are hard materials that break with sharp edges. From the practical use of individual stones as tools, weapons, and decorations, it was a big step to the wholesale mining or quarrying of rocks and minerals for building, for making clay for pottery, and then for the ores that contain metals. Today mining is done so expertly and intensively that geologists have come to concern themselves with the exhaustion of the world's valuable mineral resources: minerals of economic significance and their reserves are covered in Chapter 22.

THE MATERIALS OF EARTH

Because of the many uses of rocks and minerals, we have a practical curiosity about where they are found and how they were formed: we want to be able to find more. Yet there are other reasons, too, for rocks, as we have seen, are the only records of how the Earth evolved, and they are an important guide to how the Earth works today. For this reason, **mineralogy**, the study of minerals, and **petrology**, the study of rocks, are important subfields of geology. Finally, there is the intrinsic interest in the extraordinary range of the mineral kingdom, with its immense variety of color, form, and texture. Minerals and rocks, after all, give us the marble and alabaster of sculpture, the jade of Eastern carvings, and the pigments used by Rembrandt.

What Information Do We Want from Rocks?

If the nature of rocks is a clue to many of the things we want to know about the Earth, how do we go about interpreting it? We need a key, just as ancient historians needed the Rosetta stone to crack the "code" of Egyptian hieroglyphics before they could read that part of human history. First of all we want to find out just what the minerals are made up of and how the rock is put together from its constituent minerals. From its composition we should be able to say something about where the parent material came from and what it

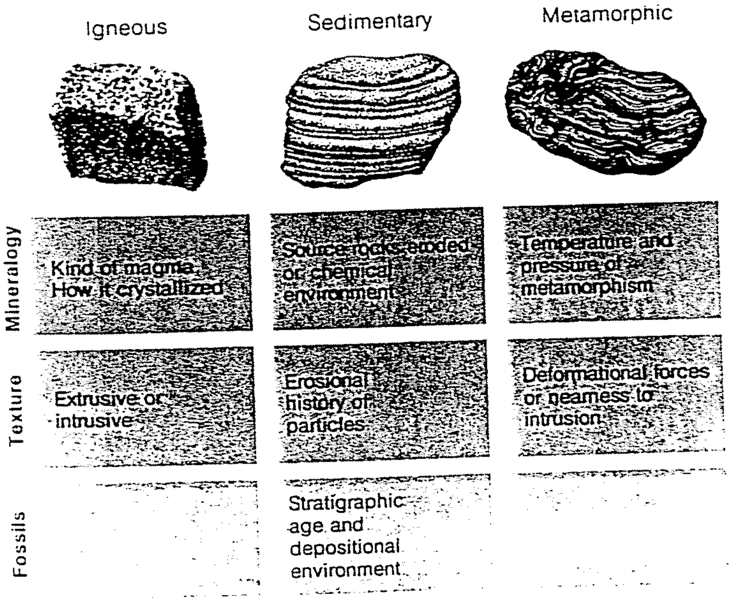

Figure 3-1
The mineralogy and texture of a rock are the keys to inferring its origin.

was like (Fig. 3-1). What was the magma like? Or. what were the source rocks of a sediment? Or. what were the preexisting rocks that were heated and compressed to make a metamorphic rock? From the composition and the texture of the rock we should also be able to tell something of the pressures and temperatures at which the rock was formed by comparing these properties with the artificial rocks and minerals made in the laboratory.

In this chapter we cover the nature of the rocks and minerals that make up the Earth's crust and mantle. We first explore the relation of rock to mineral. Next we show how the external appearance and properties of minerals are related to the way in which their fundamental building blocks—the atoms and ions of the chemical elements—are connected with each other in the internal architecture of crystals. With that picture in mind we can describe the mineralogy and textures of the three great classes of rocks.

Rocks Are Made of Minerals

A rock is many things. It is a collection of the particular chemical elements that make it up. Those elements are not found randomly mixed in a rock. but they are distributed among an assemblage of **minerals** (Fig. 3-2). A mineral is a solid chemical compound that is characterized by a definite composition or a restricted range of chemical compositions and by a specific. regular architecture of the atoms that make it up. Like all chemical compounds. minerals are homogeneous: a mineral cannot be separated mechanically into different substances. Minerals make up a rock just as bricks make up a brick wall. in a great variety of arrangements. In coarse-grained rocks the minerals are large enough to be seen with the naked eye. In some rocks the minerals can be seen to have **crystal faces.** smooth planes bounded by sharp edges: in others. such as a typical sandstone. the minerals are in the form of fragments without faces. In fine-grained rocks. the individual mineral grains

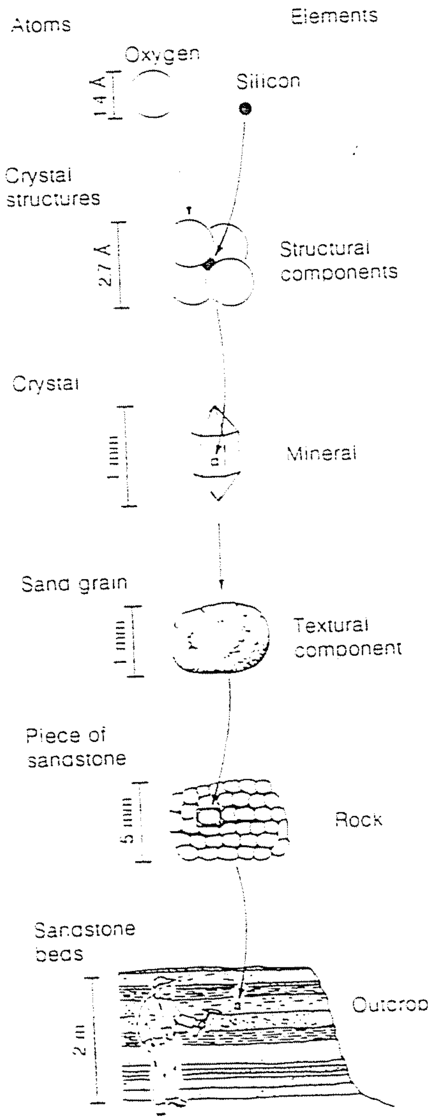

Figure 3-2
How atoms combine to form rocks. Atoms make up the small structural components that form minerals. which in turn combine to form rocks. Units of length are shown at left. Å stands for angstrom unit. 1 Å = 10^{-8} cm.

are so small that they can be seen only with a powerful magnifying glass, the hand lens that the field geologist carries. Some are so small that a microscope is needed to make them out.

On the basis of certain characteristics, particularly physical and chemical properties, several thousand minerals can be distinguished, each defined by its unique set of properties. For thousands of years, people who have used minerals—whether miners looking for iron ore minerals or artists looking for minerals to grind into pigments—have used simple physical and chemical tests to distinguish one from another. Color is one obvious characteristic. Differences in hardness were found to make it easy to distinguish between minerals that look similar. How minerals break apart, some showing smooth cleavage planes and others rough irregular fractures, proved to be a reliable way to identify certain minerals. Simple chemical tests were found useful in the field, such as dropping acid on a mineral suspected of being calcite ($CaCO_3$) to see whether the mineral would fizz as it dissolved, releasing carbon dioxide bubbles.

Early in the study of minerals it was realized that all grains or crystals of a mineral, like quartz, have just about the same qualities regardless of the kind of rock in which they are found. Some minerals, particularly those that have a more complex mixture of atoms, vary slightly in their properties, depending on their precise composition. A mineral like garnet, for example, has a number of varieties. Each variety has its own range of composition, such as the proportions of iron and other elements, and hence, its own set of properties.

Rocks are not as uniquely defined by their properties as minerals are. Because of the immense number of ways in which the thousands of minerals can be combined, the geologist is faced with a bewildering array of rock types. The only way to make order out of this array is to classify like with like and to sort out by general type (Fig. 3-3). The major division of rocks into igneous, sedimentary, and metamorphic is just such an aid. Within each major division there are many groups and types. Using characteristic properties, we can divide the rock kingdom into several hundred general types, each with its own more-or-less distinctive earmarks.

Despite all of these numbers, a remarkable amount can be done by knowing even a small number of the most common minerals and rocks. In most parts of the world a field geologist can make an accurate geologic map by knowing only a few dozen major minerals and even fewer common rock types. This simplification is possible because most of the thousands of known minerals are either rare or unusual. In addition, many minerals can be lumped into groups. Thus the geologist who can recognize garnet will do well, even though a mineral sophisticate who can distinguish the many varieties of garnet by their slightly different chemical compositions might do better. Naturally, the more we can distinguish, the more the information gleaned, and the greater the power of our theories of explanation. That is why petrologists have to know a great deal about mineralogy.

Just how do we go about identifying minerals and explaining their origins from their characteristics? In the field we still use external form and other obvious physical properties. In modern laboratories, however, advanced instruments are used to learn the basic composition and atomic architecture of minerals. These are the underlying determinants of the other properties. From analysis of crystal structure and external form, we draw the best conclusions of origin. The next sections take us from the study of crystal faces to the explanation of physical properties in terms of the atomic arrangement.

CRYSTALS: FACES AND SYMMETRY

The regularity of crystal faces is the most striking feature of the external form of minerals, and for many years minerals were studied and identified mainly by analyzing their symmetry. In addition to his earlier contributions—enunciating the laws of stratigraphy and recognizing fossils—Steno wrote in 1669 that quartz crystals, wherever found, always show the same angle between similar crystal faces. By the late eighteenth century, his *constancy of interfacial angles* became accepted as a generality applicable to all minerals. By 1801 the major work of the great crystallographer René Haüy was accomplished, all in the midst of the great upheaval of the French Revolution. Haüy summarized the laws of *crystal symmetry*, the regularities of crystal faces. That symmetry, we now know, is a manifestation of the symmetry of the arrangement of the atoms that make up the crystal. As a consequence of the work of Haüy and others, the early part of the nineteenth century was a time of intense study of the relation between the external forms of minerals and their chemical composition, a development that paralleled the great geological exploration of the Earth and the growth of the geological time scale.

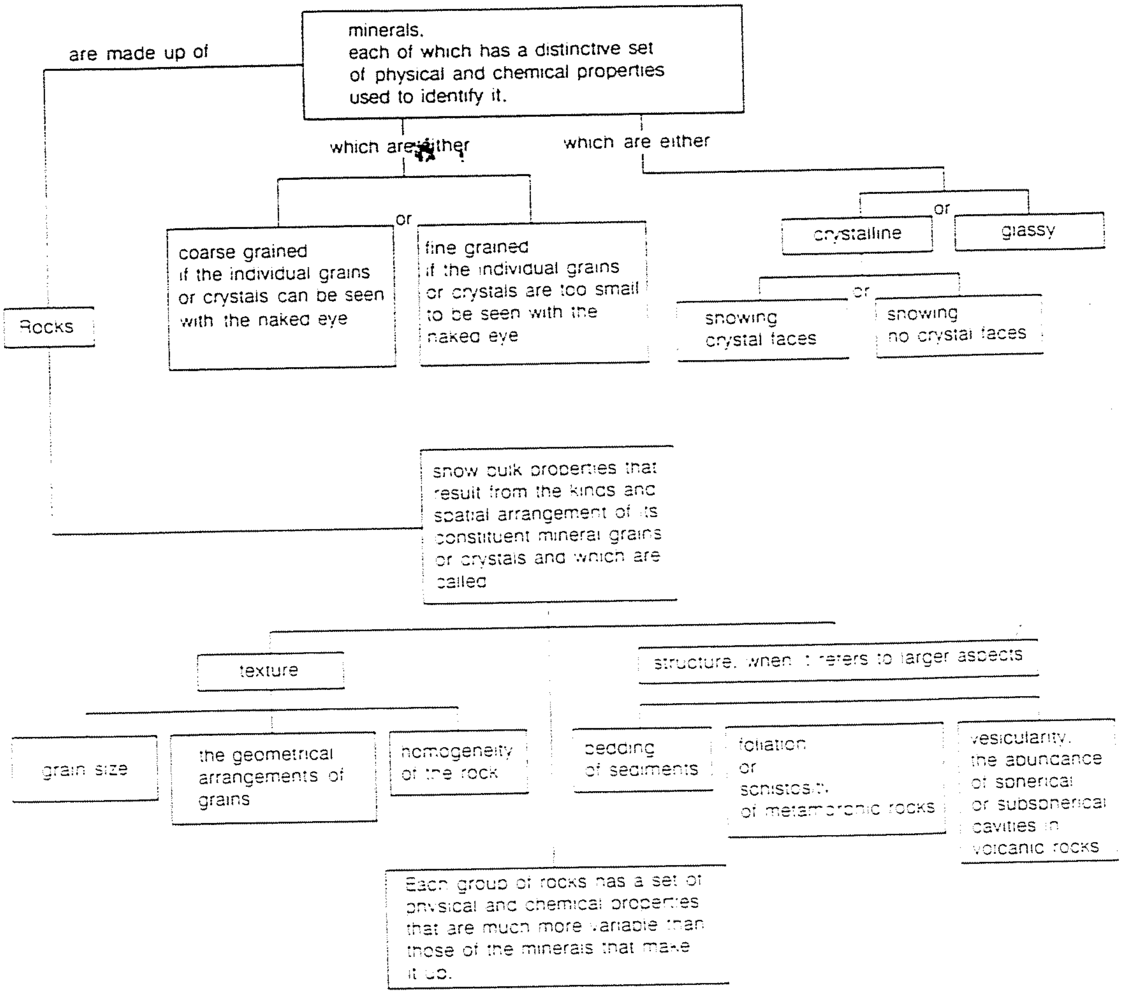

Figure 3-3
Flow chart of rock properties as determined by characteristics of the mineral constituents. The minerals ore classified both by their grain size and by crystal form. Rocks are grouped both by texture. the smaller-scale details of arrangement of mineral grains in the rock. and by structure. the larger-scale aspects of the mineral constituents.

How to Measure a Crystal

A crystal is a piece of matter whose boundaries are naturally formed plane surfaces. The geometry of a crystal may be relatively simple. as in the cubes of fluorite (Fig. 3-4) and of common salt. the mineral **halite:** or they may be beautifully complex. as in snowflakes. the crystals of ice (Fig. 3-5). Crystals are usually formed when a liquid solidifies or when a solution becomes **supersaturated**—that is. too enriched in dissolved material to hold it any longer—and the dissolved substances precipitate. or "drop." out of solution. When some liquids. such as molten silicates. congeal very quickly. the solid that forms is not crystalline but **glassy;** in this case crystals with plane faces do not form. but only masses with

Figure 3-4
Interlocking cubic crystals of fluorite. [Photo by Alfred A. Blaker.]

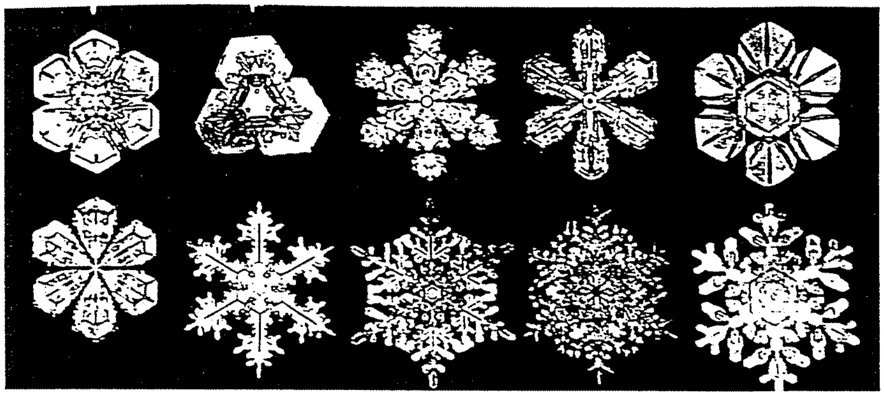

Figure 3–5
Photomicrographs of snowflake crystals. These were described as among the choicest specimens of crystal architecture in a 25-year search by Wilson Bentley, pioneer photographer of snow crystals. [Photos by Wilson Bentley, courtesy of Duncan Blanchard, State University of New York at Albany.]

Figure 3–6
Obsidian, a volcanic glass. The curved, sharply terminated fracture surfaces are typical of *conchoidal fracture*, which characterizes glasses and a number of minerals. [Photo by R. Siever.]

Figure 3–7
Quartz exhibits a variety of crystalline forms ranging from groups of crystals with well-developed crystal faces, such as those on the left, to masses of crystals intergrown in such a way that no crystal faces are developed, such as in the broken pebble of vein quartz on the right. [Photo by R. Siever.]

curved, irregular surfaces (Fig. 3–6). This absence of crystallinity is typical of quickly cooled material in many lavas. The glassy texture is the result of lack of regular, symmetric order in the arrangement of atoms.

The most useful measurements to be made on crystals are those of the angles between faces (Fig. 3–7 and 3–8). From these angles the geometry of all of the faces in relation to each other can be constructed. Haüy and other mineralogists discovered that, in addition to constancy of interfacial angles, each kind of crystal exhibits other regularities: definite symmetrical relationships exist among faces, and there are certain simple mathematical relations between the angles of all faces. The marvel of finding such simplicity in the midst of apparent complexity is what led Haüy and oth-

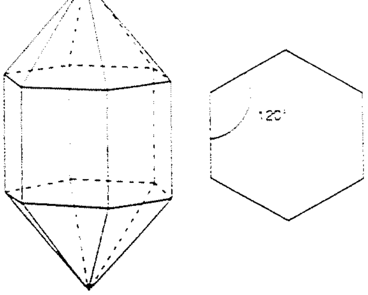

Figure 3–8
Drawing of a perfect quartz crystal. A section at right angles to the long axis shows a regular hexagon with faces at 120° angles.

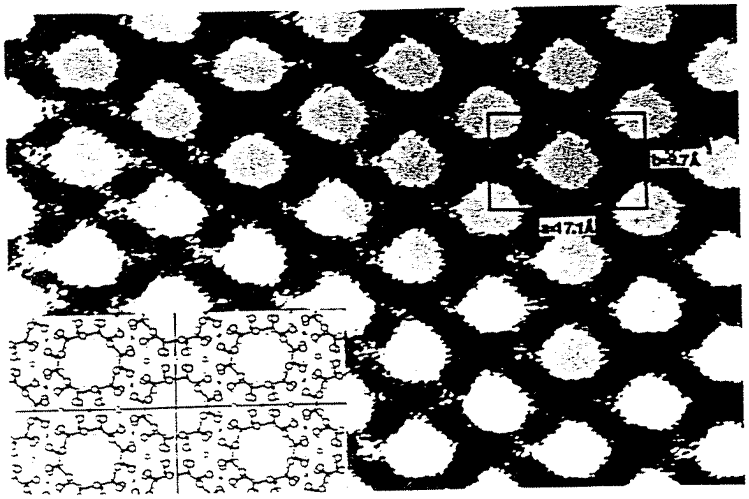

Figure 3-9
High-magnification electron micrograph of a section of the mineral cordierite, a magnesium-iron-aluminosilicate. This image was made perpendicular to one of the major axes of symmetry. The inset shows the idealized structure deduced from x-ray diffraction. [From Peter R. Buseck and Sumio Iijima, "High Resolution Electron Microscopy of Silicates," *American Mineralogist*, v. 59, 1974, Copyright © 1973.]

Figure 3-10
Microscopic view of a thin section (transparent slice) of diorite porphyry under polarizing light. The white crystals are feldspar; the large, dark, more-or-less rectangular ones are hornblende. The large crystals were all once floating in a melt, which is now represented by the fine-grained groundmass. Width of field 2.5 mm. [From *Geology of Soils* by Charles B. Hunt. W. H. Freeman and Company. Copyright © 1972.]

ers to infer that there must be an underlying order to the arrangement of the atoms in crystals—an idea that could not be verified until a century later when x rays were discovered and beamed through crystals.

Another element of order became evident after hundreds of different kinds of crystals had been measured. Mathematical analysis showed that there are only thirty-two different ways of arranging atoms about a point that will allow the building of a three-dimensional crystal that obeys symmetry rules. Measurement of angles between crystal faces and analysis of the symmetry of crystals led to a simple all-inclusive classification that consists of a limited number of major crystal systems and classes of those systems. The analysis of symmetry is still a part of modern mineralogy, though it is now studied by x-ray diffraction and electron microscopy rather than by the observation of angles between crystal faces (Fig. 3-9). Symmetry remains important because it is one of the basic clues to the pattern of regularity of the atoms in a crystal.

MINERALS AND THE MICROSCOPE

In 1858, at the end of the half century during which the modern laws of crystallography were worked out, the English geologist Henry Sorby published a memoir, *On the Microscopical Structure of Crystals*. It was Sorby's inspiration to use the knowledge that rocks become transparent if slices are ground thinly enough* and that the way crystals affect polarized light passing through them provides a means of identifying minerals and of studying the mineral compositions and textures of a wide variety of rocks. Using a polarizing microscope, Sorby could for the first time identify small grains or crystals that could be seen only with high-power magnification (Fig. 3-10).

From the various properties of minerals in polarized light, mineralogists have constructed detailed tables for the identification of crystals. Using these tables while studying thin sections of

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*Thin sections are made by cutting off a slice of rock about 1 mm thick with a saw containing embedded diamonds. One side is then ground smooth with silicon carbide grinding powders and cemented to a glass slide. Next, the open side is ground down to the desired thinness, about 0.03 mm, the last gentle stages of polishing being monitored with a microscope. Some minerals are opaque no matter how thin they are ground. These are the metallic minerals, sometimes called the *opaque minerals*. An example is pyrite, FeS_2.

rock under the microscope, the geologist can tell just what kinds of minerals are put together in a particular pattern to make up the rock.

THE ATOMIC STRUCTURE OF MINERALS

Though many nineteenth-century mineralogists, following the lead of earlier scientists, had speculated about how the atoms that make up all matter might be arranged in crystals, there was at the time no way to confirm any relation between external form and internal structure. By the beginning of the twentieth century, many mineralogists were convinced that crystal form, chemical composition, and such physical properties as color and hardness, might be explained in terms of some hypothetical atomic pattern, but they still had no proof. That proof was provided in 1912 by the German physicist Max von Laue and two of his students when they irradiated a crystal of copper sulfate with x rays and produced an x-ray diffraction pattern on a film placed behind the crystal. Von Laue reasoned that if ordinary light could be **diffracted**—that is, deflected around corners to give a pattern of fringes when it is directed through very tiny openings such as pinholes or slits—so could x rays beamed through crystals. Von Laue guessed that if the mineralogists were right in their speculations about crystals being orderly arrangements of atoms, the pattern of x rays could reveal how the atoms are arranged in space. Only one year after that remarkable and crucial experiment, an English father-and-son team, William H. Bragg and William L. Bragg, published the first crystal-structure analysis of a mineral, halite. The Nobel Prize in physics was awarded to the Braggs for this work in 1915 when the younger Bragg, William L., was only twenty-five.

In the next dozen years a great many minerals were structurally mapped. This work paved the way for the Norwegian mineralogist and petrologist V. M. Goldschmidt to outline, in 1926, all of the general principles governing the ways that the atoms of different elements are assembled to form crystals. Finally, some explanation could be given for the long-known facts of the external appearance of crystals and their properties. The explanation lies in the structure of atoms, their systematic changes with increasing atomic number and atomic weight, their atomic size, and their ability to form various kinds of chemical bonds with other atoms.

The Gain and Loss of Electrons

As we noted in Chapter 2, an atom consists of a cloud of electrons around a relatively small nucleus of protons and neutrons. An atom may gain or lose one or more electrons, thus forming an **ion**, charged positively or negatively depending on the relative numbers of protons in the nucleus and electrons surrounding the nucleus. The number of protons remains the same, even though electrons may be lost or gained. A positively charged ion, a **cation**, has lost electrons: a negatively charged ion, an **anion**, has gained electrons.

Working out the rules that describe how electrons are tied to the nucleus was a major part of the business of atomic physics early in this century. Contemporary concepts of atomic structure picture the locations of electrons around the nucleus as orbitals whose shapes and sizes depend upon the energy level of the electron. The ease with which electrons are gained or lost is described in terms of the electronic structure of the elements, in which orbitals are represented as simple electron "shells"—spheres about the nucleus whose radii are proportional to their energy levels (see Fig. 2-24).

The elements can be classified on the basis of electronic structure (Table 3-1 and Fig. 3-11). One small set includes the elements whose outermost shell is populated by eight electrons. They are the *noble gases:* neon, argon, krypton, xenon, and radon. Because this is a stable configuration, these elements have little tendency either to gain or to lose electrons, and so do not form any important crystalline compounds. Helium, with only two electrons, is also stable and belongs with this group.

Another set of elements is made up of those whose outermost shells may gain or lose electrons. These elements include most of the common abundant ones, such as sodium, potassium, magnesium, calcium, and chlorine. These elements have a tendency either to gain or to lose electrons in order to assume the stable configuration of the inert gases. When a chlorine atom gains an electron, it becomes the chloride anion with eight electrons in the outer shell, thus achieving the same electronic structure as that of argon. Similarly, the element potassium has a strong tendency to lose an electron and form a cation with exactly the same structure as the chloride ion. The electrons that are gained and lost, called **valence electrons,** determine the chemical behavior of the elements.

Other elements have very weak tendencies to

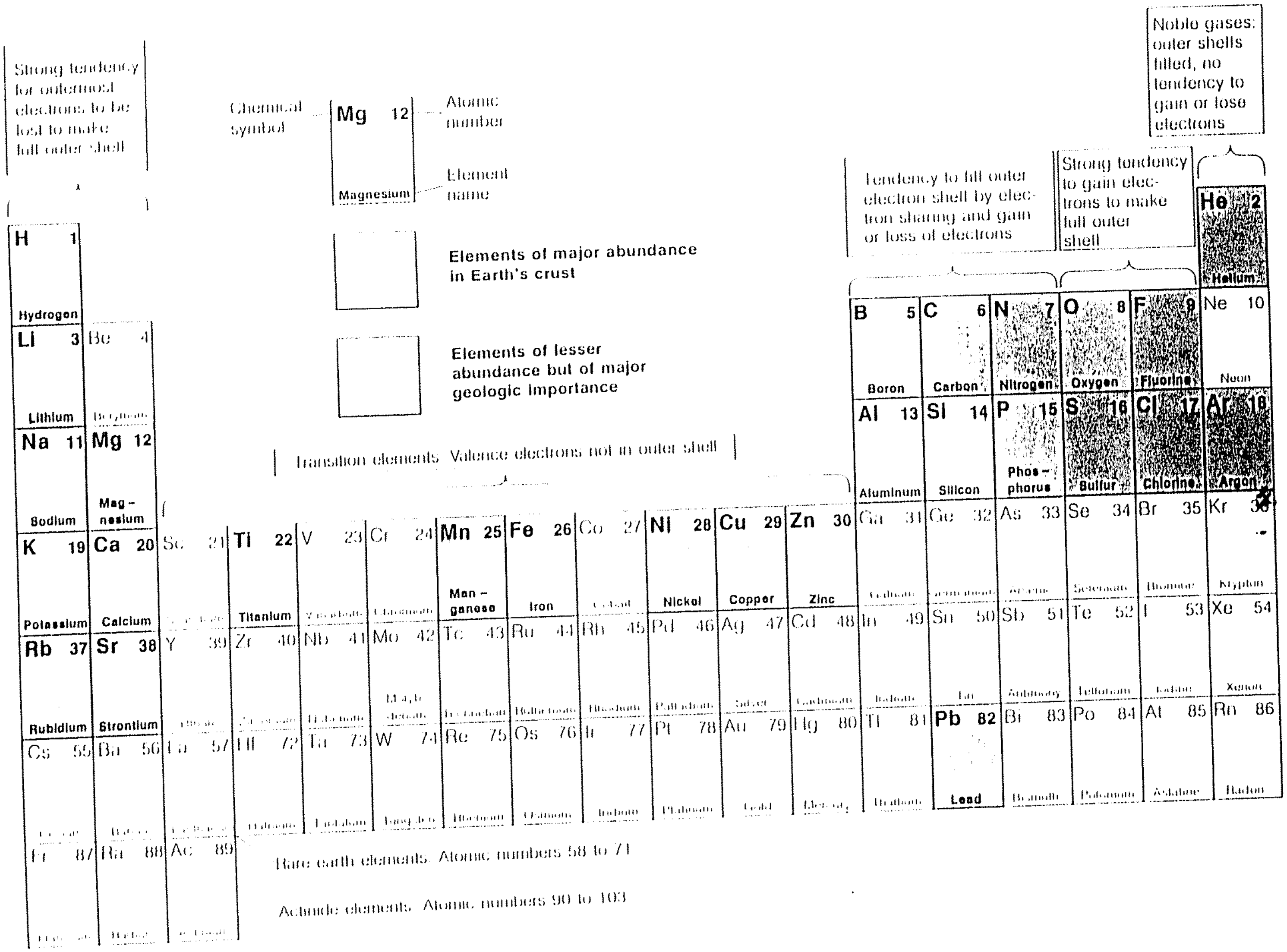

Figure 3-11
Periodic table of the elements (rare earth and actinide elements omitted). The elements of lesser abundance in the Earth's crust but of major geologic importance are those that are constituents of common rock-forming minerals or are of economic significance.

Table 3-1
Types of electronic structure of the elements (other than rare earths or actinides)

Type of element	*Common elements*	*Characteristics*
Noble gases	Helium, argon	Outer shells of elements have stable, filled configurations and no tendency to form chemical compounds.
Alkali metals Alkaline Earth metals	Sodium, potassium Calcium, magnesium	Outer shells have one or two valence electrons and strong tendency to lose them and form cations
Halogen group Oxygen group	Fluorine, chlorine Oxygen, sulfur	Outer shells need one or two electrons to attain stable configurations and have strong tendency to gain electrons and form anions
Boron group Carbon group Nitrogen group	Boron, aluminum Carbon, silicon Nitrogen, phosphorus	Outer shells tend to attain stable configurations by sharing electrons with other atoms and have weak tendency to gain or lose electrons
Transition elements	Iron, copper, zinc	Valence electrons tend to be gained or lost from an inner shell rather than the outer shell

gain or lose valence electrons but strong tendencies to share them with atoms of the same or different kind, thus achieving a stable configuration. In electron sharing, a shared electron cannot be considered to have been gained or lost. In a sense, both nuclei have "gained" the electron for whatever part of the time that it can be visualized as belonging to the one or the other nucleus. Carbon and silicon are two important elements in this group.

The transition elements are those whose valence electrons are in the next-to-outermost shells. These elements may form several different kinds of ions; iron, for example, forms two cations, Fe^{2+} and Fe^{3+} (see Chapter 4).

The importance of electronic structure, shells of valence electrons, and stability of the outer shell is that they all determine the nature of chemical bonding of one element to another in crystals. There are a number of bond types, and they are not mutually exclusive. A particular bond may be largely of one type but have some characteristics of another.

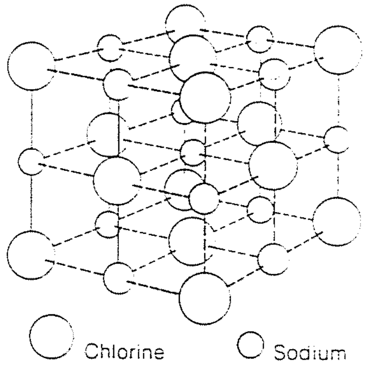

Figure 3-12
Cubic structure of sodium chloride.
The lines between ions are drawn only to show the geometry of the cubic outlines. Ions not drawn to scale.

Ionic Bonds

The simplest form of chemical bond, in some ways, is the **ionic bond.** Bonds of this type are formed by electrostatic attraction* between ions of opposite charge. This attraction is of exactly the same nature as the attraction that makes hair stand up when some synthetic fabrics are drawn over it. Ionic bonds form most strongly between elements like sodium and chlorine, which have a strong tendency to gain or lose electrons and become cations or anions. In fact, the simplest of all ionically bonded crystalline substances is sodium chloride, whose crystal structure was the first to be worked out. From a look at Figure 3-12 one can see the symmetry of the ionic arrangement, that each ion of one kind is surrounded by six of the other. There is no "molecule" of NaCl as such. The six neighbors give rise to a new measure, the **coordination number.** Both sodium and chloride ions are in six-coordination. The six-sided figure defined by the lines joining the anions (chloride) that surround the cation (sodium) is an octahedron with the anions at the corners. In the same way, other simple geometric figures correspond to

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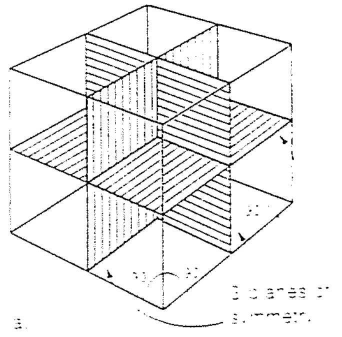
*Electrostatic attraction is described by *Coulomb's law:* the attraction (or repulsion) between two charged particles is directly proportional to their product and inversely proportional to the square of the distance between them.

$$E = k(q_1 \times q_2)/d^2$$

where E is the attractive force, the q's the number of charges on the ions or electrons, d the distance, and k a proportionality constant associated with the medium in which the attraction takes place. The value of k is 1 in a vacuum.

Box 3-1 CRYSTAL SYMMETRY

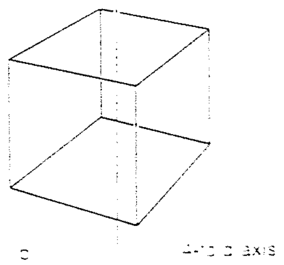
One can see how a simple crystal is analyzed by taking a cube and noting, first, the obvious relation that all faces are always at 90° to each other and, second, that there are three mutually perpendicular imaginary planes such that each is a *plane of symmetry*; that is, each face on one side of the plane is mirrored on the other side. Or, one can hold opposite faces of the cube on an axis between thumb and forefinger and spin it around to find that there is a *fourfold axis of symmetry*; that is, in one complete rotation of 360° a face will be repeated four times. Another axis of rotation between opposite corners is a three-fold axis of symmetry. The essence of symmetry is this: a simple geometrical operation can be performed that will repeat a face in another position. To put it another way, if one performs an operation such as a rotation, a new face will occupy the same position that was occupied by another face before rotation—and one cannot distinguish the final appearance from the original one.

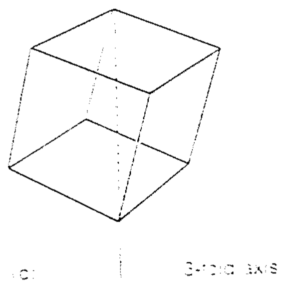


Crystal systems

System	*Minimum symmetry*	*Reference axes*
Isometric	4 3-fold axes	3 mutually perpendicular; all of same length
Trigonal	1 3-fold axis	4 axes, 3 horizontal with 120° intersections, 1 vertical. Horizontal axes all of same length; vertical axis any length
Hexagonal	1 6-fold axis	Same as trigonal
Tetragonal	1 4-fold axis	3 mutually perpendicular; 2 of same length, 3rd of any length
Orthorhombic	3 2-fold axes or 3 symmetry planes	3 mutually perpendicular; each of any length
Monoclinic	1 2-fold axis and/or 1 symmetry plane	2 axes at oblique angle, 3rd axis perpendicular to plane of the other 2; each axis of any length
Triclinic	1-fold axis or center of symmetry	3 axes at oblique angles; each of any length

Note: In some classifications, hexagonal and trigonal are considered to be divisions of one crystal system, the hexagonal.





other coordination numbers: 3 for the anions at the corners of a triangle and 4 for the anions at the corners of a tetrahedron (Fig. 3-13). The coordination number can be estimated from the relative sizes of the ions. The **ionic radius** varies among the elements depending on atomic number and ionic charge of the ion. Comparisons between ions are then expressed as a **radius ratio**, the ratio of the cation radius to the anion radius. In general, the larger the radius ratio, the larger the coordination number. Though there are many additional complexities, mineralogists have been able to predict a large number of structures based on these criteria alone.

Cations are small, most of them less than 10^{-8} centimeters in radius. But most anions are large, as is the most common anion in Earth, oxygen. From this fact it is apparent that most of the space of a crystal is occupied by the anions and that the cations fit into spaces between them. Figure 3-14 shows the NaCl structure with ions of approximately the correct size.

Covalent Bonds

Compounds that achieve a stable electronic configuration by sharing electrons rather than gaining

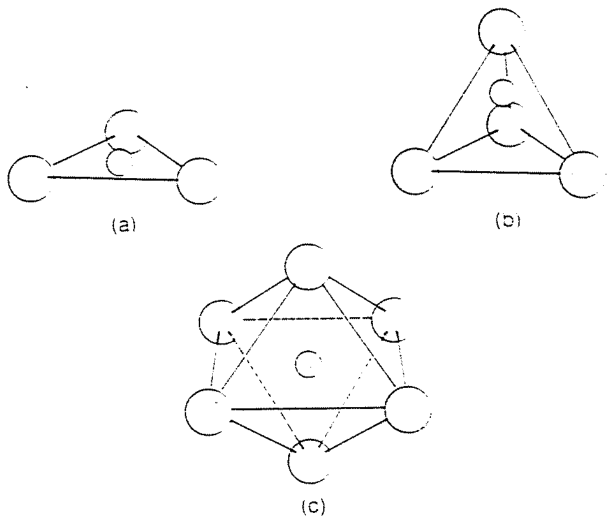


Figure 3-13
Coordination numbers correspond to regular geometric figures defined by lines joining the anions that surround a cation (small dark circle). (a) Coordination number 3 gives a plane triangle; (b) coordination number 4 gives a tetrahedron; (c) coordination number 6 gives an octahedron.

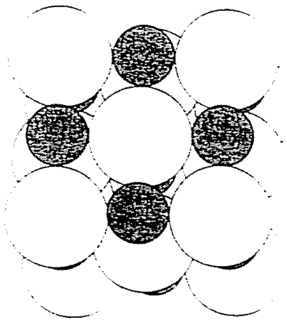


Figure 3-14
Cubic structure of sodium chloride, showing the ions in their correct relative sizes.

or losing them are held together by **covalent bonds.** The formation of such bonds depends on the number and distribution of shared electrons in the outer shells, and so the kinds of compounds and crystal structures formed are determined by more complex factors than the simple geometric ones determined by the ionic bonds in crystals. Elements that do not readily gain or lose electrons to form ions—for example, carbon—form bonds of this kind. The simplest covalent structure is that of diamond, in which every carbon atom (not an ion) is surrounded by four others (coordination number 4) arranged in a regular tetrahedron. When coordinated in this way, each carbon atom shares an electron pair with each of its four neighbors and thus achieves a stable octet of electrons in its outer shell.

The van der Waals Bond

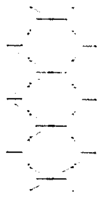
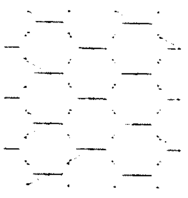
Much weaker bonds than ionic or covalent bonds exist between all ions and atoms in solids. They are named after the man who inferred their existence from weak attractive forces shown by atoms and molecules in gases. The **van der Waals bond** is a weak electrical attraction that is related to the asymmetry of certain atoms and ions. They play a role of moderate importance in some silicate minerals, where their presence is not masked by the more powerful ionic and covalent links.

The Structures of Some Common Minerals

Though the variety of known structure types in the universe is great, geologists usually encounter only a relatively small number, largely because most rocks are made up of silicate minerals, composed of the two most abundant elements in the Earth's crust, oxygen (O) and silicon (Si). Silicates are of a few main structure types. The basis for all silicate structures is the radius ratio of silicon to oxygen, about 0.30, which allows each silicon to be four-coordinated to four surrounding oxygens in a regular tetrahedron (Fig. 3-13). Silicate structures are made up of these tetrahedra arranged in different ways, with such cations as sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), ferrous iron (Fe^{2+}) and ferric iron (Fe^{3+}) in the interstices (spaces) between. The bond between Si and O is about half ionic in character and half covalent, the Si sharing one of its outer electrons with each oxygen ion. Adjacent silicons may share oxygen ions, allowing networks of several kinds to be built up of tetrahedra. Many silicate minerals also contain aluminum, the third most abundant element in the Earth's crust. The radius ratio of aluminum to oxygen is 0.36, close enough to the silicon-oxygen ratio to allow aluminum to take the place of silicon ions in a tetrahedral structure. The ratio is large enough, however, to allow aluminum to be octahedrally coordinated too, like the ions in NaCl, and it may join adjacent tetrahedra by a largely ionic bond.

Cations that have similar coordination numbers and similar ionic radii tend to substitute for each other and make mixed compounds that we call *solid solutions*, which are analogous in every way to common liquid solutions. Natural olivines are

Table 3–2
Major silicate structures

Geometry of linkage of SiO_4 tetrahedra	*Si/O ratio*		*Example mineral*	*Formula*
Isolated tetrahedra: linked by bonds sharing oxygens only through cation	1:4		Olivine	$(Mg,Fe)_2SiO_4$
Rings of tetrahedra: joined by shared oxygens in 3-, 4- or 6-membered rings	1:3		Beryl	$BeAl_2(Si_6O_{18})$
Single chains: each tetrahedron linked to two others by shared oxygens. Chains bonded by cations	1:3		Pyroxene	$(Mg,Fe)SiO_3$
Double chains: 2 chains joined by shared oxygens as well as cations	4:11		Amphibole	$(Ca_2Mg_5)Si_8O_{22}(OH)_2$
Sheets: each tetrahedron linked to 3 others by shared oxygens. Sheets bonded by cations or alumina sheets	2:5		Kaolinite	$Al_2Si_2O_5(OH)_4$
Frameworks: each tetrahedron shares all its oxygens with other SiO_4 tetrahedra (in quartz) or AlO_4 tetrahedra	3:8 1:2		Feldspar (Albite) Quartz	$NaAlSi_3O_8$ SiO_2

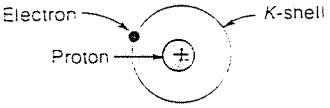
solid solutions of variable amounts of iron and magnesium silicates. The pure magnesium olivine is Mg_2SiO_4, forsterite: the pure iron olivine is Fe_2SiO_4, fayalite. The composition of the natural solid-solution mineral is represented by the formula $(Mg, Fe)_2SiO_4$, which simply means that there are two magnesium or ferrous ions, in whatever combination, for every silicate group.

Silicates are classified and named according to the way the tetrahedra are linked, as shown in Table 3–2. Isolated tetrahedra are linked by mutual bonding to a cation between. Rings of tetrahedra are formed by bonding of two oxygens of each tetrahedron to adjacent tetrahedra in closed rings. Single chains form by the same linkage. In some minerals two single chains are combined to form double chains, in which the chains are linked by cations. Sheets are structures in which each tetrahedron shares three of its oxygens with adjacent tetrahedra to build planar lattices. In three-dimensional frameworks, the tetrahedra are linked by sharing oxygens with other tetrahedra. Aluminum may substitute for silicon in chains, sheets, and frameworks.

A different sort of building block is the carbonate ion. In this group of ions the carbon atom is surrounded by three oxygen atoms in a planar triangle. Groups of carbonate ions are arranged in sheets in a manner somewhat like that of the sheet silicates. The mineral calcite is made up of car-

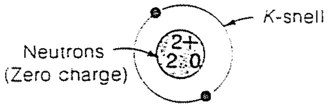
Box 3–2 ELECTRONIC STRUCTURE OF THE ELEMENTS

The hydrogen atom is the smallest and simplest of all atoms, having just one proton in the nucleus and just one orbiting electron (atomic number Z-1). Electron orbits correspond to "shells" around the nucleus, for electrons do not follow a simple, single path as the planets do around the Sun but can be considered to occupy, at various instants, points on a sphere, or spheres, around the nucleus. As atomic number increases, so does the number of electrons and the number of shells. The table lists the shells and the maximum number of electrons each can hold. The single hydrogen electron occupies the **K-shell**, the innermost of the seven shells. The element of next higher atomic number is helium, which has two electrons, both in the K-shell (Z = 2). The K-shell can be occupied by only two electrons. The element of next higher atomic number, lithium, has three electrons (Z = 3), one of which occupies the next shell outward, the ***L*-shell**. This shell can hold eight electrons. The first two shells, K and L, fill up in order as the atomic number of the elements increases from hydrogen to neon. After that, from sodium (Z = 11) to argon (Z = 18), the next eight electrons start to fill up the ***M*-shell.** Then the regular order is interrupted and the ***N*-shell** starts to fill before the M-shell is completed. Then electrons are added to both M and N shells, until M is filled, whereupon with increasing atomic number, the **O-shell** starts filling and N continues being completed. This complication of shell filling helps to explain why the chemistry of the heavier elements is somewhat more varied and complex than that of the light elements, those with only two or three shells.

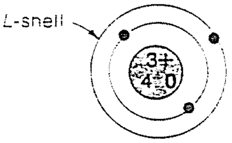


Hydrogen atom
Net charge (1+) + (1−) = 0
Atomic number 1

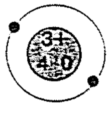
Hydrogen ion, a cation (*K*-electron lost)
Net charge (1−)
Atomic number 1



Helium atom
Net charge (2+) − (2−0) − 2(−) = 0
Atomic number 2



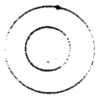
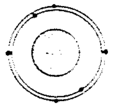
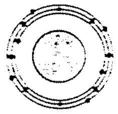
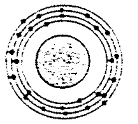
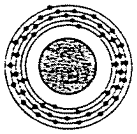
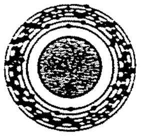
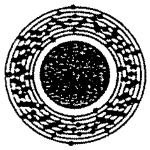
Lithium atom
Net charge (3+) + (4−0) − (3−) = 0
Atomic number 3



Lithium ion, a cation (*L*-electron lost)
Net charge (3+) + (4−0) + (2−) = (1+)
Atomic number 3

As atomic number increases, electrons fill up the innermost, or K-shell, first, and then start to fill the L-shell. Ions are formed when atoms lose or gain electrons.

Electron shells of atoms

Shell	*Maximum number of electrons possible in shell*		*Example*
K	2		Hydrogen *K*-1
L	8		Carbon *K*-2, *L*-4
M	18		Silicon *K*-2, *L*-8, *M*-4
N	32		Iron *K*-2, *L*-8, *M*-14, *N*-2
O	50		Silver *K*-2, *L*-8, *M*-18 *N*-18, *O*-1
P	72		Gold *K*-2, *L*-8, *M*-18 *N*-32, *O*-18, *P*-1
Q	98		Uranium *K*-2, *L*-8, *M*-18, *N*-32, *O*-21, *P*-9 *Q*-2

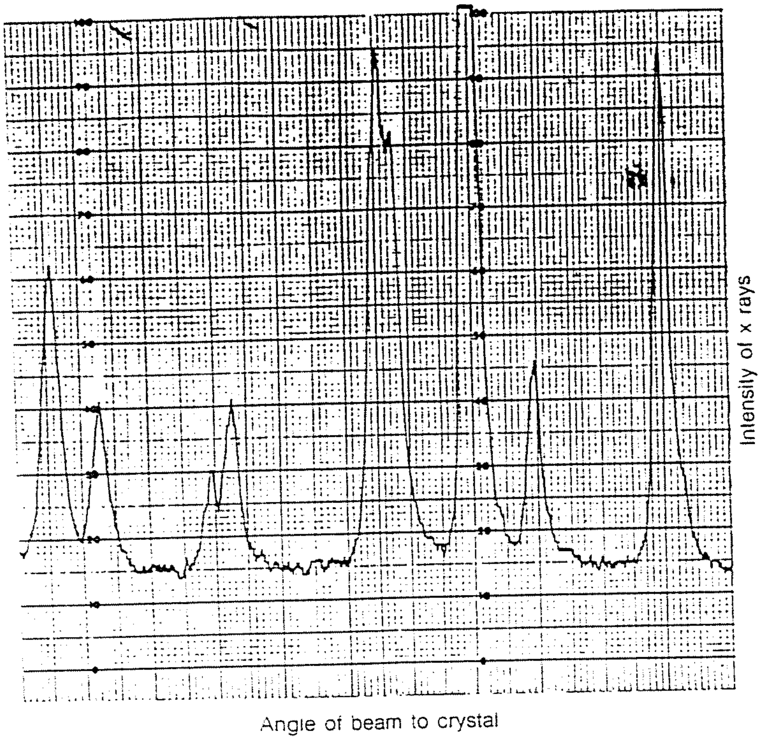


Figure 3-15
An x-ray diffraction pattern of a feldspar produced by an x-ray beam from various planes of atoms in the crystal as the crystal is rotated in the x-ray beam. The peaks correspond to reflections from particular planes, some more strongly reflecting than others.

bonate sheets and intervening planes of calcium ions. The mineral dolomite is made up of the same carbonate sheets separated by alternating sheets of calcium and magnesium ions.

Glasses lack the regularity of structure that is typical of the crystalline state. In silica glass, for example, the atoms are arranged in silica tetrahedra, but instead of being linked in a regular repetitive manner, they are more or less randomly arranged, as they would be in a liquid.

All natural crystal structures have a variety of defects and imperfections. These are the result of disturbances of the ordered arrangement of atoms by dislocations, which are small "faults," by holes where atoms are missing, or by places of misfit around an impurity atom or point of disorder. These defects, as well as the specific nature of crystal faces, can be related to the conditions for crystal growth and thus are clues to the environment in which the crystal grew. Since this is the petrologist's goal in understanding how rocks form, the study of the imperfections in crystal structure is becoming almost as important as the study of regularity and symmetry.

This brief tour through the world of crystal structures is intended to give some idea of the power of the principles of atomic physics, crystallography, and mineralogy, for it is from these disciplines that we have learned the extraordinary details that enable scientists to explain how crystals are put together. Now that you have some idea of what is known about structure, it is possible to show how x-ray diffraction was used to learn it all.

X RAYS: THE DIAGNOSTIC TOOL OF MINERALOGY

Soon after von Laue discovered x-ray diffraction, W. L. Bragg found that a pattern of diffraction corresponded to one that would be formed by reflection of the x-ray beam from planes within the crystal, the reflection angles following certain mathematical requirements. The many lines of reflection that are found on x-ray patterns each come from one of the planes (Fig. 3-15). The patterns of the lines can be used to find a probable crystal structure. Today crystal structures are analyzed by computer-controlled x-ray diffraction equipment. The results are fed into another computer that spins out a complete structure analysis, possibly even with crystal drawings.

X rays are used as a rapid means of identifying minerals by their structures. They can be so used because no two minerals have precisely the same x-ray pattern, even though they may have the same structure type. The precise pattern of sheet silicates, such as the micas, muscovite, and biotite, differ. The spacings and the intensity of the reflections depend on the kinds of atoms as well as their arrangement, so each mineral is distinctive. Today the x-ray machine is used for simple mineral identification almost as routinely as the somewhat crude physical and chemical tests were used in the last century. X-ray equipment, however, is not easily carried into the field, even though some semiportable units have been invented, so it is still necessary to learn the simple diagnostic features of the common minerals (Appendix IV).

PHYSICAL AND CHEMICAL PROPERTIES OF MINERALS

A few years ago in Quincy, Massachusetts, a scratched message was discovered on the window of a house that John Hancock had owned in the eighteenth century. Speculation was that Hancock had scratched his and a woman's initials on the glass with his diamond ring. Whoever made

Table 3-3
Bond types and physical properties

Property	*Ionic*	*Covalent*	*van der Waals*
Structural types	Bond strength of any ion is uniform in all directions with high coordination numbers	Interatomic or ionic bonds are strong only in a few set directions, hence coordination numbers low	Bond strength of any ion is uniform in all directions with high coordination numbers
Hardness	Strong bonds give high hardness	Stronger bonds, in general, giving higher hardness than ionic bonds	Weak bonds give low hardness
Cleavage	Ease of cleavage, ranges poor to good; depends on distance between planes of atoms and individual bond strengths		Excellent cleavage
Melting points	Moderate to high; ions are present in the melt	Very high; molecules are present in melt	Low

Source: After R. C. Evans, *An Introduction to Crystal Chemistry*, 2nd ed., Cambridge University Press, Oxford, 1966.

the inscription perhaps knew that a diamond is the hardest mineral known and can easily scratch glass. What makes diamond so hard was then unknown. People also knew that mica, the sheety mineral commonly used for oven and lantern windows at that time, cleaves easily into paper-thin sheets as transparent as window glass, but they did not know why. They were aware of many distinctive and useful properties of minerals. The earliest and still the simplest ways of identifying many common minerals are based upon their hardness and cleavage and upon other physical properties.

Physical Properties, Bond Types, and Structures

We now know that the way atoms and ions are bound has a direct effect on their physical properties, as shown in Table 3-3. Few bonds are exclusively ionic or covalent; instead, most are hybrids. For this reason, the correlation with properties is only a weak generalization. Particular properties of a specific mineral can be explained on the basis of the kinds of atoms it is composed of and the bond types between atoms.

A good example is the mineral talc, of which talcum powder is made. Talc is composed of silicate layers weakly bonded to each other by van der Waals forces. Because they are so weakly bonded, the layers slip and break apart easily. It is that easy slippage of one layer over the other that gives talc its soapy feel and that makes it grindable to a fine, smooth, cosmetic powder. Beryl, whose clear, deep-green variety is emerald, is also a sheet silicate, but the bonds between the sheets in beryl are strong, predominantly ionic. As a result, the mineral is hard and breaks with difficulty in any direction.

Table 3-4
Mohs scale of hardness

Mineral	*Scale number*	*Common objects*
Talc	1	
Gypsum	2	Fingernail
Calcite	3	Copper wire or coin
Fluorite	4	
Apatite	5	Pocket knife
Orthoclase	6	Window glass
Quartz	7	Steel file
Topaz	8	
Corundum	9	
Diamond	10	

*Mohs arranged the scale so that the hardness difference between any two adjacent minerals is about the same, except for the difference between corundum and diamond, which is much greater. Mons could not find a mineral of intermediate hardness, nor has anyone else.

Hardness

Just as a diamond scratches glass, so will a quartz crystal scratch a feldspar crystal because one is harder than the other. In 1822 Friedrich Mohs, an Austrian mineralogist, devised a scale of hardness based on the ability of one mineral to scratch another, that spanned the spectrum from the softest to the hardest mineral known (Table 3-4). Even with all of the elegant instruments now available to determine hardness by indentation or scratching, the **Mohs scale of hardness** remains the best practical way to identify an unknown mineral. A combination of common objects and a few of the minerals on the hardness scale are all one needs to bracket an unknown mineral between two points on the scale.

The hardness of any mineral depends on the strength of the bonds between ions or atoms; the stronger the bonds, the harder the mineral. Be-

Box 3-3 PROPERTIES OF ROCK-FORMING SILICATES

The major groups of silicates illustrate the influence of crystal structure and chemical composition on the properties of these important rock-forming minerals (See Table 3-3 and Appendix IV). Garnets and olivines are the two chief groups of silicates built of isolated tetrahedra linked by cations. Both groups are strongly bonded in all directions and moderately closely packed, so that they are hard and have no cleavage. The density of these minerals, relatively high, depends on both packing and chemical composition; in particular it depends upon the amount of iron present. Colors are also influenced by iron content. Olivines melt at very high temperatures; hence it is not surprising that they are found in high-temperature igneous rocks rich in iron and magnesium. Garnets are chemically complex; their composition reflects the bulk composition of the metamorphic rocks in which they are usually found.

Pyroxenes (single chains of tetrahedra) and amphiboles (double chains) are much more chemically varied than the olivines or garnets. Both structures are packed moderately closely, and the presence of iron makes both these groups fairly dense and moderately hard. But the cleavage of both is good parallel to the silicate chains, for across these surfaces bonds are weaker than the strong silicon-oxygen bonds of the tetrahedral chains. The two differ in cleavage angle because of the varying angles made by single and double chains. Pyroxenes have high melting points and are most likely to be found in igneous and high-temperature metamorphic rocks rich in iron and magnesium. The stability of amphiboles over large ranges of temperature and pressure is related to their chemical composition and its effect on the compactness of the structure and to the bond strengths between cations of different kinds.

Micas (sheet silicates) show the most striking dependence of physical properties on structure: their perfect cleavage is due to the weak bonds between sheets, where the weakly bonded cations, such as potassium, are held. The minerals are relatively low in density and light in color, except for biotite, the iron species. The micas are found in many different igneous, metamorphic, and sedimentary rocks, a fact related to the large range of temperatures and pressures over which they can be formed.

Feldspars, the most abundant of the silicates, have relatively simple compositions; they are made up of silicon-oxygen and aluminum-oxygen tetrahedra linked in three-dimensional frameworks, with the tetrahedra bonded to potassium (orthoclase, microcline, sanidine) and/or to sodium and calcium (plagioclase feldspars). Plagioclases range from albite, the pure sodium form, to anorthite, the pure calcium form. The strongly bonded silicon-oxygen and aluminum-oxygen framework gives these minerals their hardness and high melting temperatures. The cleavages are along planes of relatively weaker bonds between cations. There is sufficient variation in the way the three elements can combine to produce a wide range of melting temperatures and pressures; thus feldspars are characteristic of many kinds igneous, metamorphic, and sedimentary rocks, from the highest-temperature volcanics to the lowest-temperature sediments.

cause bond strengths may differ along the various crystallographic axes, hardness may also vary slightly in direction. Among the silicates hardness varies from 1 in talc to 8 in topaz. The strongest bonds are those of tetrahedrally linked Si and O. In quartz all bonds are of that type. In other silicates the Si and O atoms are also bonded to other elements, and it is those weaker bonds that determine the lower hardness. Metallic minerals may be difficult to scratch because they deform plastically; that character gives metals their malleability or ductility, properties that allow metals to be rolled into thin sheets or drawn into wires. In more brittle materials, hardness is small-scale breakage. The more ionic the bonding, the greater the brittleness, and most minerals tend to be somewhat brittle.

Cleavage

The term used for breakage along definite planar surfaces, typified by that of mica, is **cleavage.** The number of planes of cleavage varies among minerals. The cleavage planes of a mineral have some of the same characteristics as its crystal faces, though they are not to be confused with them. Cleavage planes always occupy definite and constant angles—as do interfacial angles of crystal faces—with respect to the symmetry or crystallographic axes of the crystal and are parallel to a possible crystal face.

Cleavage is the expression of differing bond strengths along the various planes of a crystal. The bonds across some of those planes may be very weak, like the van der Waals bonds that are

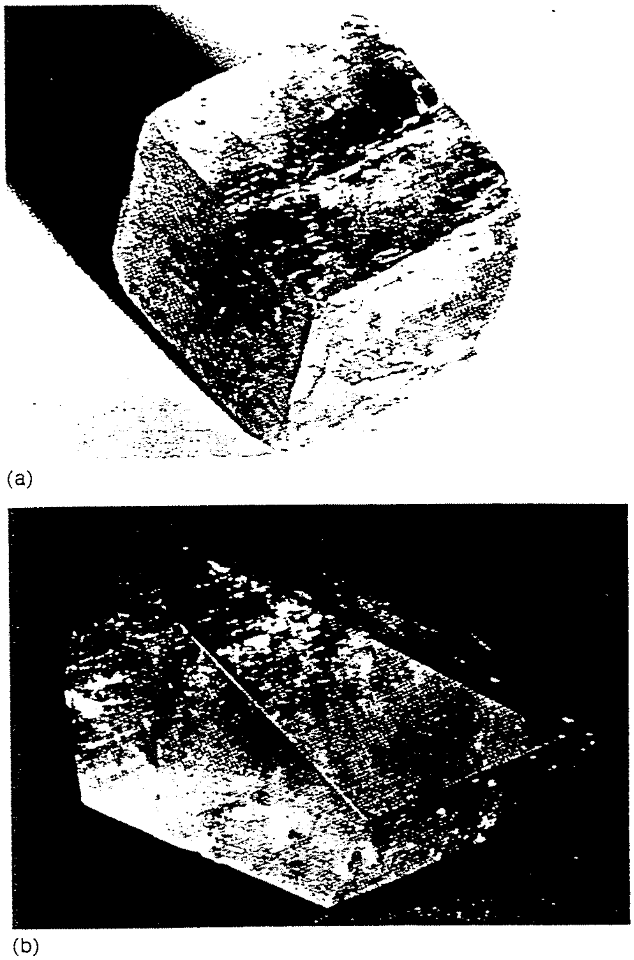


Figure 3–16
Calcite crystals. (a) A cleavage rhombohedron whose surfaces were made by breaking the crystalline material along zones of weak bonding strength in the crystal. (b) Faces formed by growth of the crystal from solution. [From *Dana's Manual of Mineralogy* (16th ed.) by C. S. Hurlbut, Jr., copyright © 1952, John Wiley & Sons.]

responsible for the easy breakage across the cleavage planes of mica. Calcite has three excellent cleavages parallel to the faces of a rhombohedron, the result of weak bonds (Fig. 3–16). Quartz is strongly bonded in all directions and has no good cleavage. Cleavage can be scaled on the basis of ease of cleaving with a chisel, from the most *perfect cleavages* of the micas to the *fair cleavage* of beryl (emerald). The most expert cleaving in the world is done in Amsterdam, where the center of the diamond "cutting" industry is; it is the excellent cleavage of diamond along many planes that makes possible the shaping of the hardest mineral known, for there is nothing harder with which to cut it!

Distinctive patterns of cleavage are identifying hallmarks of a number of common rock-forming minerals. Calcite and dolomite are easily recognized by their rhombohedral cleavage faces. Galena, lead sulfide, cleaves perfectly into cubes. Two important groups of silicates that frequently look alike otherwise, pyroxenes and amphiboles, can be distinguished on the basis of their cleavage patterns. Pyroxenes, single chains of silica tetrahedra, are bonded so that two good cleavage directions are almost at right angles (93°), whereas amphiboles, double chains, bond to give two cleavage directions at 56°.

Some minerals reveal the character of their bonding by bending rather than breaking. Bonds that are mainly covalent are stronger in one direction than another. In mica, the bonds along the sheets of the structure maintain themselves while the weaker bonds between sheets allow bending. Micas are elastic: they spring back after bending. Other sheet silicates, like chlorite, are flexible: once bent, they remain that way.

Fracture

The way in which minerals break other than along cleavage planes also serves to group them and help in identification. **Fracture** may be *conchoidal*, showing smooth, curved surfaces like those of a thick piece of broken glass (see Fig. 3–16); *fibrous* or *splintery*, *hackly* (from hackles, the stiff hairs or spines of some animals), and *uneven* or *irregular*, all of which are descriptive, though imprecise, terms. Geometric properties of such variability and irregularity as fracture still defy the attempts of scientists to devise simple, quantitative measures to make the description objective and uniform. The type and irregularity of fracture bears a complex relation to the breaking of bonds in directions that cut across crystallographic planes. In minerals whose bond strengths are about the same in all directions, fracture patterns depend on the abundance, kind, and distribution of submicroscopic fractures and crystal defects.

Streak

The name **streak** is given to the color of the fine powder that is produced when a mineral is scraped across a tile of unglazed porcelain, called a streak plate. The color is diagnostic for many minerals; for example, the iron oxide, hematite, always gives a reddish-brown streak regardless of the color of the particular mineral aggregate being streaked, which may be black, red, or brown.

Table 3–5
Mineral luster

Metallic:	strong reflections produced by opaque substances.
Vitreous:	bright, as in glass.
Resinous:	characteristic of resins, such as amber.
Greasy:	surface has the appearance of being coated with an oily substance.
Pearly:	the whitish iridescence of materials like pearl.
Silky:	the sheen of fibrous materials like silk.
Adamantine:	the brilliant luster of diamond and similar minerals.

Luster

How the surface of a mineral reflects light gives it a characteristic **luster.** Mineral lusters are described by the terms in Table 3-5. The quality of light reflected from mineral surfaces is controlled by the index of refraction. That property, in turn, is related not only to the kinds of atoms present but to their bonding. For example, covalently bonded minerals tend toward adamantine luster, whereas ionically bonded minerals are more vitreous. Other lusters are related to irregularities of the surface.

Color

In July 1976 we found out from the Viking landing on Mars that the "red planet" really is red. The surface materials have a strong reddish hue that probably comes from hydrated ferric oxides. The same materials, thrown into the Martian atmosphere by strong winds, give the Martian sky a pinkish color. Many minerals show a characteristic color on freshly broken surfaces; others show characteristic colors on weathered or altered surfaces. We use not only the colors reflected from mineral surfaces but also the colors transmitted through minerals in microscopic thin sections. Color seen in thin sections is a good, quick guide to the identification of certain minerals. Some minerals—for example, precious opals—show a stunning play of colors on reflecting surfaces. Others change color slightly with a change in the angle of the light shining on the surface. Color may be a property of the pure substance or it may be the result of impurities. The color of pure substances is dependent on the presence of certain ions, such as iron or chromium, which strongly absorb certain colors of light. Most ionically bonded minerals with stable configurations of outer electron shells are colorless. Color is more characteristic of such minerals as olivine, which have bonds to transition elements (in this case iron) whose valence electrons are in an inner shell. Impurities, often too small to be seen except by the most powerful microscope, such as small dispersed flakes of hematite in a quartz crystal, impart a general color to an otherwise colorless mineral.

Specific Gravity and Density

Although the obvious difference in weight of a piece of hematite iron ore and a piece of sulfur of the same size is easily felt by hefting the pieces, a great many common rock-forming minerals have about the same range of **density** (= mass/volume). Consequently, methods were needed that would make it easy to measure that property of minerals accurately. The standard measure of density is **specific gravity,** which is weight of the mineral in air divided by the weight of an equal volume of water at 4°C. The specific gravity is usually determined by measuring the weight of the mineral in air and in water. The difference between the two weights is equivalent to the weight of the equal volume of water. Because density not only is useful in identifying minerals but also depends strongly on the internal structure and composition of the substance, it has been measured accurately for most minerals.

Density is dependent on the atomic weight of the constituents and the tightness of packing of the atoms in the crystal structure. The iron minerals hematite and magnetite have high densities because of the high atomic weight of iron. Metals tend to have close-packed structures and therefore high densities. Covalently bonded structures tend to be more open and to have lower densities.

Density is also affected by pressure, and pressure-induced increases in density affect how rocks and minerals transmit light, heat, and elastic waves, such as those associated with earthquakes (see Chapter 17). Some chemical substances form more than one kind of crystal: the different kinds of crystals are called **polymorphs.** Calcium carbonate, for example, forms both calcite (density 2.71), and aragonite (density 2.93). The denser aragonite is known from experimentation to form and remain stable at high pressures, whereas calcite forms and is stable at low pressures.

Chemical Properties

The chemical compositions of minerals are the basis for the main classification of the mineral

Table 3-6
Chemical classes of minerals*

Class	*Defining anions*	*Example*
Native elements	None: no charged ions	*Copper*, Cu
Sulfides and similar compounds	Sulfide: S^{2-} and similar anions	*Pyrite*, FeS_2
Oxides and Hydroxides	O^{2-} OH^-	*Hematite*, Fe_2O_3 *Brucite*, $Mg(OH)_2$
Halides	Cl^-, F^-, Br^-, I^-	*Halite*, NaCl
Carbonates and similar compounds	CO_3^{2-}	*Calcite*, $CaCO_3$
Sulfates and similar compounds	SO_4^{2-} and similar anions	*Barite*, $BaSO_4$
Phosphates and similar compounds	PO_4^{3-} and similar anions	*Apatite*, $Ca_5F(PO_4)_3$
Silicates (see Table 3-2 for details of silicates)	SiO_4^{4-}	*Pyroxene*, $MgSiO_3$

*This classification, derived originally by Berzelius in the nineteenth century and used extensively by Dana, is a simplified form of the scheme used by Berry and Mason in *Elements of Mineralogy*, W. H. Freeman and Company, 1968.

kingdom. The chemical criterion used to classify the minerals is the anion of the mineral.* For example, halite, NaCl, is classed as a chloride, as is its close relative, sylvite, KCl. In this way, all minerals have been grouped into eight classes, as shown in Table 3-6.

Most of what we know about the chemical composition of minerals was gained through the use of ordinary wet chemical methods, by which materials are dissolved, separated into their constituent elements, and their weights or volumes then measured. Various other methods have been added over the past few decades as chemical instruments became more capable of measuring small quantities of elements in new ways. In the last twenty years the electron probe, a device that beams electrons at a sample mineral and analyzes the x rays generated, has been used to get good chemical analyses of very small crystals. Most recently it has been joined by the ion probe, which beams energetic ions at a mineral target and analyzes the resulting radiation from the constituent elements.

Mineralogists have also relied for many years on quick, simple chemical tests that can be made in the field. One such is the "acid test," in which dilute hydrochloric acid (HCl) is dropped on a mineral to see if it fizzes. If it does, it is likely to be calcite, a carbonate mineral.

All natural minerals contain impurities, enough of them so that it is frequently hard to decide whether an element is an integral part of the mineral or merely an extraneous contaminant. Elements that make up much less than 0.1 percent of the mineral are reported in analyses by the word "trace," and many elements are called **trace elements.** But most trace elements we rarely hear about, for they are neither abundant in the Earth (or the solar system) nor do they have any important industrial use. Typical of these are lanthanum (La), one of the rare earth elements, and scandium (Sc), an element that has affinities with aluminum and boron. Trace elements are analyzed by means of a number of instruments, most commonly by an emission spectrograph—an instrument that vaporizes the mineral with an extremely hot electric arc and then analyzes the light emitted by the burning substance. Also important is x-ray fluorescence, in which irradiation by x rays excites secondary radiation characteristic of an element. In another analytical method, neutron activation, an atomic reactor is used to bombard the mineral with fast-moving neutrons. Some of the originally nonradioactive elements in the mineral are changed into new, radioactive elements. The abundance of the new elements can then be analyzed by their radioactivity. One different atom among a billion others can be detected in this way.

Another part of chemical analysis is the determination of the relative proportions of different isotopes, the elements with the same atomic number (protons) but different atomic weights. In Chapter 2, we discussed the use of radioactive isotopes in dating rocks, but there are other isotopes

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*The names "anion" for negative ion and "cation" for positive ion date back to early experiments with electrochemical cells, the ancestors of modern automobile batteries. Because the cathode, the negatively charged electrode, attracts positive ions, those ions became called *cations*. Similarly, the *anode*, the positively charged electrode, attracts negative ions, hence anion.

of some elements that are stable—that is, nonradioactive. Three of the most important are the heavy stable isotope of carbon, ^{13}C, the heavy stable isotope of oxygen, ^{18}O, and the heavy stable isotope of sulfur, ^{34}S. The study of these isotopes in minerals, in the atmosphere, and in natural waters has contributed greatly to geology. For example, the ratio of ^{18}O to ^{16}O has been used to determine ancient temperatures. The $^{18}O/^{16}O$ ratio in calcium carbonate ($CaCO_3$) depends on the temperature of the water from which the carbonate precipitated. Thus a fossil oyster shell can be analyzed using a mass spectrometer to learn the temperature of the sea in which the animal lived.

ROCKS AS MINERAL AGGREGATES

The architecture of a rock is not unlike that of a building—a design of building blocks assembled in certain ways. The building blocks of a rock, of course, are minerals. Without too much difficulty, we might be able to think of an enormous number of ways of putting minerals together, but most of the arrangements would bear little relation to anything we find in nature. The problem, then, is to find out the designs of nature and to learn why there are certain ways in which minerals are put together to form rocks and why there are many, many other ways in which they are not. Much of this book is devoted to questions such as these.

Rocks are first subdivided on the basis of origin. The three major categories of rock are igneous, metamorphic, and sedimentary. Origin is determined by a combination of rock characteristics, such as bedding, the layering that indicates a sedimentary origin; foliation, the preferred orientation of crystals that indicates a metamorphic origin; and a variety of other textures and structures. Although there are some differences in mineral composition among the three rock types, it is more useful to discuss mineralogical and textural attributes for each major group separately. Once the igneous, metamorphic, and sedimentary rocks have been described, it will be easier to see how the three groups can be distinguished from each other.

The Igneous Rocks

The igneous rocks can be subdivided on the basis of the minerals of which they are composed, the chemistry of the rocks serving as a clue to the composition of the magmas from which they solidified. One of the first criteria used when the igneous rocks were first studied in the last century was the amount of silica, SiO_2, in the chemical analysis. During that premodern period of chemistry, the silica was thought to be derived from silicic acid, and so the more silica in the rock, the more "acidic" the magma was said to be. **Granite,** rich in silica, is the most abundant acidic rock. The rocks lower in silica were called basic. **Gabbro,** poor in silica, is the "basic" counterpart of granite. We now know that silica content is not a measure of acidity as that word is used in chemistry, but the terms persist even though what we really mean is "more or less **silicic.**" The amount of silica is not necessarily related to the amount of quartz for much of the silica may be combined in other silicate minerals. In the classification by silica content, the coarse-grained igneous rocks range in sequence from granite on the more silicic side, through **granodiorite** and **diorite,** to gabbro on the less silicic side.

The modern system of classifying the major groups, based on their chemistry and mineralogic composition, turns out to be much the same as the classification by silica content. The two terms most commonly used today, come from a broad division into light and dark minerals—and rocks—called, respectively, **felsic** and **mafic.** These terms were used because the dominant minerals of the light group are quartz and feldspars, both rich in silica (hence "felsic," from *fel*(s), feldspar, plus *ic*) and those of the dark group are pyroxenes, amphiboles, and olivines, all of which are rich in magnesium and iron (hence "mafic," from *ma*gnesium and *f*errous for iron, plus *ic*). The terms felsic and mafic are also used for rocks. Figure 3-17 shows graphically the division of igneous rocks according to their mineral content and their grain size. The varieties of feldspar are most important in the classification of the igneous rocks, both because they are abundant and because the proportions of different kinds of feldspar vary systematically from felsic to mafic rocks. Granite, at the left in Figure 3-17, is rich in potassium feldspar (mainly the mineral orthoclase), whereas the more mafic rocks, on the right, are dominated by sodium and calcium feldspars, the plagioclases. The less dark rocks are dominated by biotite mica and amphibole, and darker, more mafic rocks by pyroxene and olivine. Pyroxene and olivine are the major minerals of the **ultramafic** rocks, which are even lower in silica than the basalts and gabbros; **peridotite** is mainly olivine and pyroxene and **dunite,** olivine.

The other major basis for classification of the igneous rocks is, as already described in Chapter

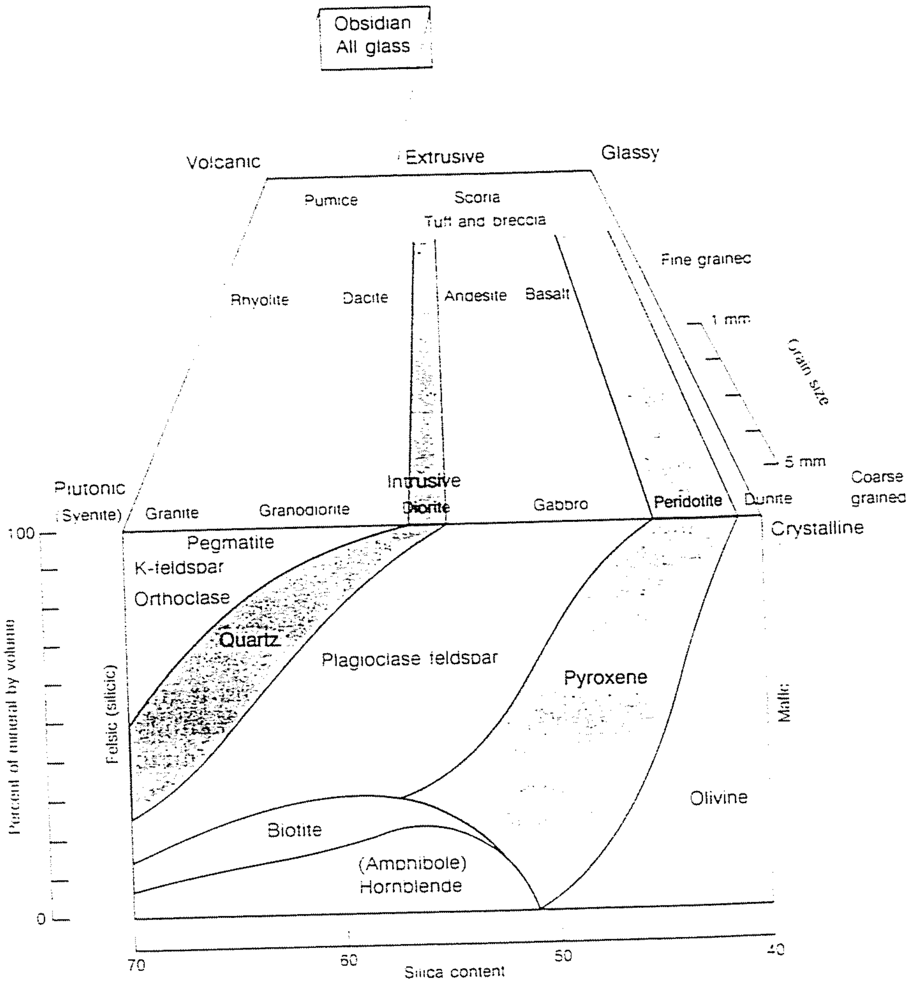


Figure 3–17
Igneous rock classification. On the front face of the cube the mineral composition is plotted as percent by volume of a given mineral for a rock of given silica content (horizontal axis). Thus a granodiorite of about 60% silica content (as determined by chemical analysis and plotted at 60% on the horizontal scale) would contain about 15% hornblende, 12% biotite, 50% plagioclase feldspar, 18% quartz, and 5% K-feldspar. On the top of the block, textures are shown: front to back is grain size, corresponding to plutonic-intrusive-crystalline at front and to volcanic-extrusive-glassy at back. Thus grandiorite is coarse grained, and dacite is the fine-grained extrusive equivalent.

2, textural. We differentiate between the coarse-grained granular rocks, or **phanerites** (from the Greek, *phanero-*, meaning visible), and the fine-grained **aphanites** (from the Greek *aphan-*, meaning invisible). A textural property that is in some ways a crystallographic property is the degree of **glassiness,** more commonly described by the opposite quality, the **crystallinity.** Both grain size and crystallinity are products of the speed with which a magma cools. The more rapid the cooling, the finer the grain size and the poorer the crystallinity. The slowest-cooling magmas congeal in the last stages of intrusion, when magmas become less viscous and contain more dissolved gases. These give rise to **pegmatites,** very coarse-grained rocks that may include crystals as much as several meters across. The fastest-cooling magmatic materials, of course, are those that are thrown high into the sky, where they instantly freeze to glass. In Figure 3–17, the top surface of the cube adds the dimension of texture to the compositional classification.

The granular or coarse-grained igneous rocks are subdivided on the basis of the abundance of their characteristic minerals, which are easily identifiable in coarse crystalline form in the field. The fine-grained igneous rocks, the volcanics, are more difficult to subdivide in the field because their minerals and glasses are not so easily identified. Their textures, however, are a good basis for grouping. Some volcanic rocks (covered in more detail in Chapter 15) may show the texture of **pyroclastic** rocks. These result from volcanic explosions that expel magma that quickly cools to glass as in the May 1980 explosion of Mt. St. Helens. The finest fragments make **volcanic ash** and **dust.** Many larger particles are also formed. Mixtures of these components are agglomerations of pieces of glass, crystals that had started to form before the explosion, and fragments of previously cooled lava. The glass may be in the form of fragments of **pumice,** a frothy mass of glass with a great number of bubbles formed by gas escaping from the melt. The sharp, spiky glass fragments are called **shards.** The bubble holes in pumice and other extrusive rocks are **vesicles.** The solidified rocks that harden from ash falls and ash flows and all of the other varieties of ejected material are lumped under the term **tuff.**

The other major textural class of volcanics includes the lavas that flow from volcanoes or large fissures in the crust. The lavas have been given Hawaiian names: **pahoehoe** for the smoother, ropy kind, and **aa** for the sharp, spiky, more jagged kind (see Chapter 15). The differences in their appearance and structure are related to the lava's viscosity, which in turn is determined by the magma's composition. These rocks may be broken and recemented by fresh lava flows, forming a **breccia.**

The lavas and pyroclastics are named for their mineral and chemical compositions in the same way as the coarse-grained series, but fewer subdivision names are in common use. **Basalts,** the most abundant of volcanic types, are chemically the equivalents of gabbros but of finer texture, and **andesites** correspond to diabases and other rocks intermediate between granite and gabbro (Fig. 3-17). On the felsic side, **rhyolite** is the aphanitic counterpart of granite, and **dacite** the aphanitic counterpart of granodiorite. The chemical elements are distributed differently between glass and minerals in an aphanite than among minerals in the corresponding granular rocks. Thus the mineral compositions of the corresponding glassy and granular rocks are not exactly the same.

There are no minerals in the entirely glassy rock **obsidian,** which is an equivalent of granites and granodiorites. The glassy, sharp, broken edges of this highly silicic glass made it perfect for Indian arrowheads. The pumices, frothy glasses, are commonly silicic also.

Many igneous rocks are made up of a mixture of both large and small crystals. If some crystals are distinctively larger than the surrounding mass, or **matrix,** they are called **phenocrysts.** A rock with many phenocrysts is called a **porphyry.** The matrix of a porphyry may consist of coarse or fine crystals or, in volcanics, glass.

Putting together mineralogy and texture gives us a scheme of classification like the one shown in Figure 3-17. The mineralogical parameter measures the proportions and kinds of felsic and mafic minerals: and the textural parameter, grain size. As is true of most classifications, the rocks do not all fall neatly into pigeonholes, for composition and texture vary continuously, and we draw arbitrary dividing lines between them to preserve as nearly as possible the traditional meanings of names that have accumulated over two centuries of geological usage.

The Sedimentary Rocks

Mineralogy and texture are also useful in subdividing the sedimentary rocks (Fig. 3-18). They are used in combination to set apart two main groups, the detrital and the chemical. The **detrital sediments** are those that carry the earmarks of the mechanical transportation and deposition of the debris of erosion, **detritus,** by currents. The minerals are fragments of rocks or minerals broken and eroded from preexisting rocks, and so are called **clastic** (from the Greek *klastos,* to break). The rocks of which ancient mountains worn down by erosion were composed can be reconstructed from the minerals of detrital rocks. Quartz, feldspar, and the clay minerals make up the bulk of that contribution. The fragments tend to wear, and abrasion during transportation rounds the particles. During sedimentation, currents **sort** the minerals by size and weight with variable efficiency: the stronger the current, the larger the particle size carried. Size and sorting of clastic sedimentary particles are characteristic of the nature of the currents that carried them. As shown in Figure 3-18, these features also form the basis for subdividing the detrital sediments into (1) coarse-grained, the gravels and their hardened, or **lithified,** equivalents, the **conglomerates:** (2) medium-grained, the sands and **sandstones:** and (3) fine-grained, clays and muds and their lithified equivalents, the **shales. Mudstone** is a general term for rocks composed of more than 50 percent clay and silt. Shales are characterized by **fissility,** a splitting along bedding plane surfaces. Coarse sedimentary rocks composed of sharp, angular pieces of rocks and minerals are breccias, which contrast with the rounded pebbles and

7

Attachment 7

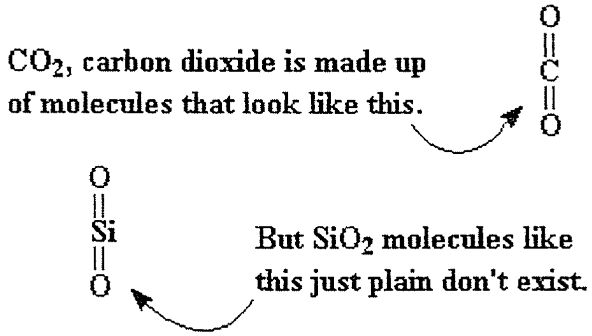
"Is Glass a Ploymer?"
(Univ. of So. Miss., Dept. of Polymer Science, 1997)

Is Glass a Polymer?

Keywords:
amorphous, crystal

We talk about glass from time to time when we're discussing polymers, especially when we're talking about composite materials. Glass fibers are often used to reinforce polymers. But what is this stuff called glass? We use it with polymers a lot, obviously, but is glass itself a polymer?

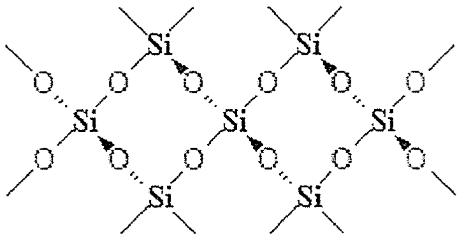
Before we tackle that question, let's take a look at what glass is. The highest quality glass has a chemical formula of SiO_2. But this is misleading. That formula conjures up ideas of little silicon dioxide molecules, analogous to carbon dioxide molecules. But little silicon dioxide molecules don't exist.



CO_2, carbon dioxide is made up of molecules that look like this.

But SiO_2 molecules like this just plain don't exist.

Instead, in nature SiO_2 is often found as a crystalline solid, with a structure like you see on your right. Every silicon atom is bonded four oxygen atoms, tetrahedrally, of course; and every oxygen atom is bonded to two silicon atoms. When SiO_2 is in this crystalline form we call it *silica*. You've seen silica before. When you find big honkin' crystals of it we call it quartz. When we have a lot of little tiny crystals of it, we call it sand.

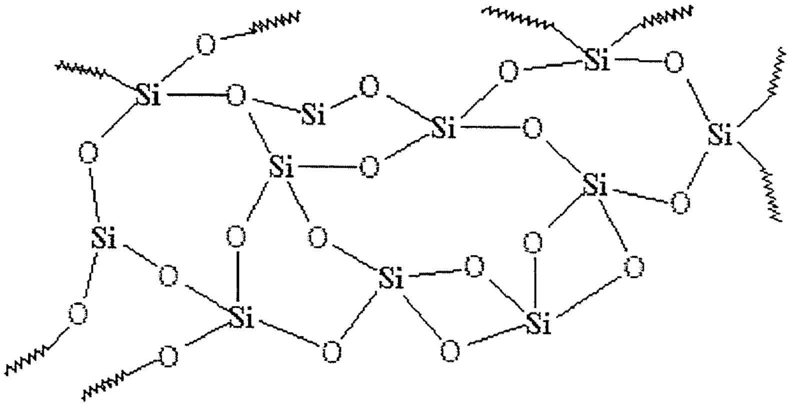


SiO_2 in it's crystalline form, quartz.

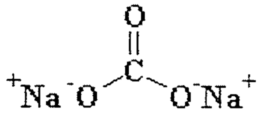
But this silica isn't glass. We have to do something to it first to make it into glass. We have to heat it up until it melts, and the cool it down really fast. When it melts, the silicon and oxygen atoms break out of their crystal structure. If we cooled it down slowly, the atoms would slowly line up back into their crystalline arrangement as they slowed down. (Remember, heat is nothing but the random motion of atoms and molecules. Hot atoms move a lot, cold atoms move very little.)

But if we cool it down fast enough, the atoms of the silica will be halted in their tracks, so to speak. They won't have time to line up, and they'll be stuck in any old arrangement. They'll

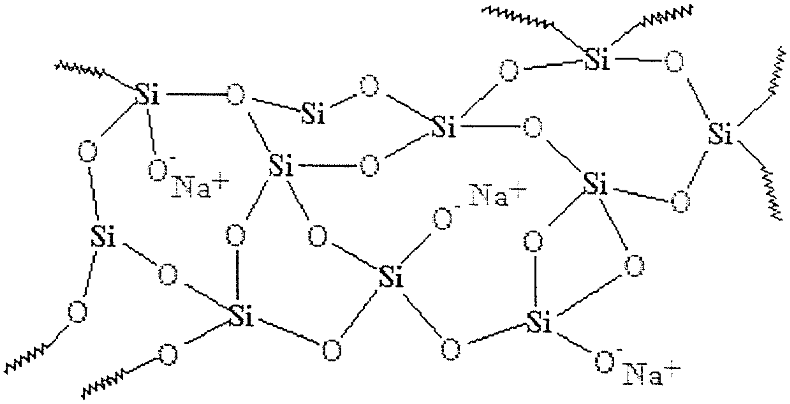
look something like this:



As you can see, there is no order to the arrangement of the atoms. We call materials like this *amorphous*. This is the glass that is used for telescope lenses and such things. It has very good optical properties, but it is brittle. For everyday uses, we need something tougher. Most glass is made from sand, and when we melt down the sand, we usually add some sodium carbonate. This gives us a thougher glass with a structure that looks like this:

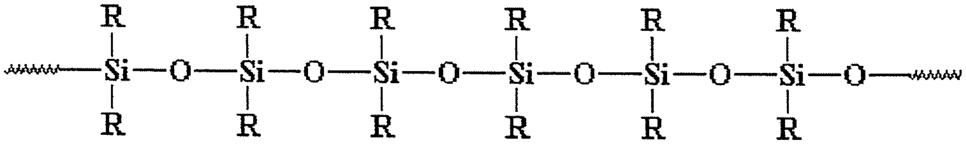


sodium carbonate



This is the glass you see everyday, in jars and windows, and it's the glass that is used in composites.

So is this a polymer or not? Usually it isn't considered as such. Why? Some may say it's inorganic, and polymers are usually organic. But there are many inorganic polymers out there. For example, what about polysiloxanes? These linear, and yes, inroganic materials have a structure very similar to glass, and they're considered polymers. Take a look at a polysiloxane:



$$\sim\!\underset{R}{\overset{R}{\mathrm{Si}}}-O-\underset{R}{\overset{R}{\mathrm{Si}}}-O-\underset{R}{\overset{R}{\mathrm{Si}}}-O-\underset{R}{\overset{R}{\mathrm{Si}}}-O-\underset{R}{\overset{R}{\mathrm{Si}}}-O-\underset{R}{\overset{R}{\mathrm{Si}}}-O\!\sim$$

So glass could be considered a highly crosslinked polysiloxane. But we usually don't think of it that way. Why? I'm not really sure. Got any ideas? Email us at *michlvic@whale.st.usm.edu*

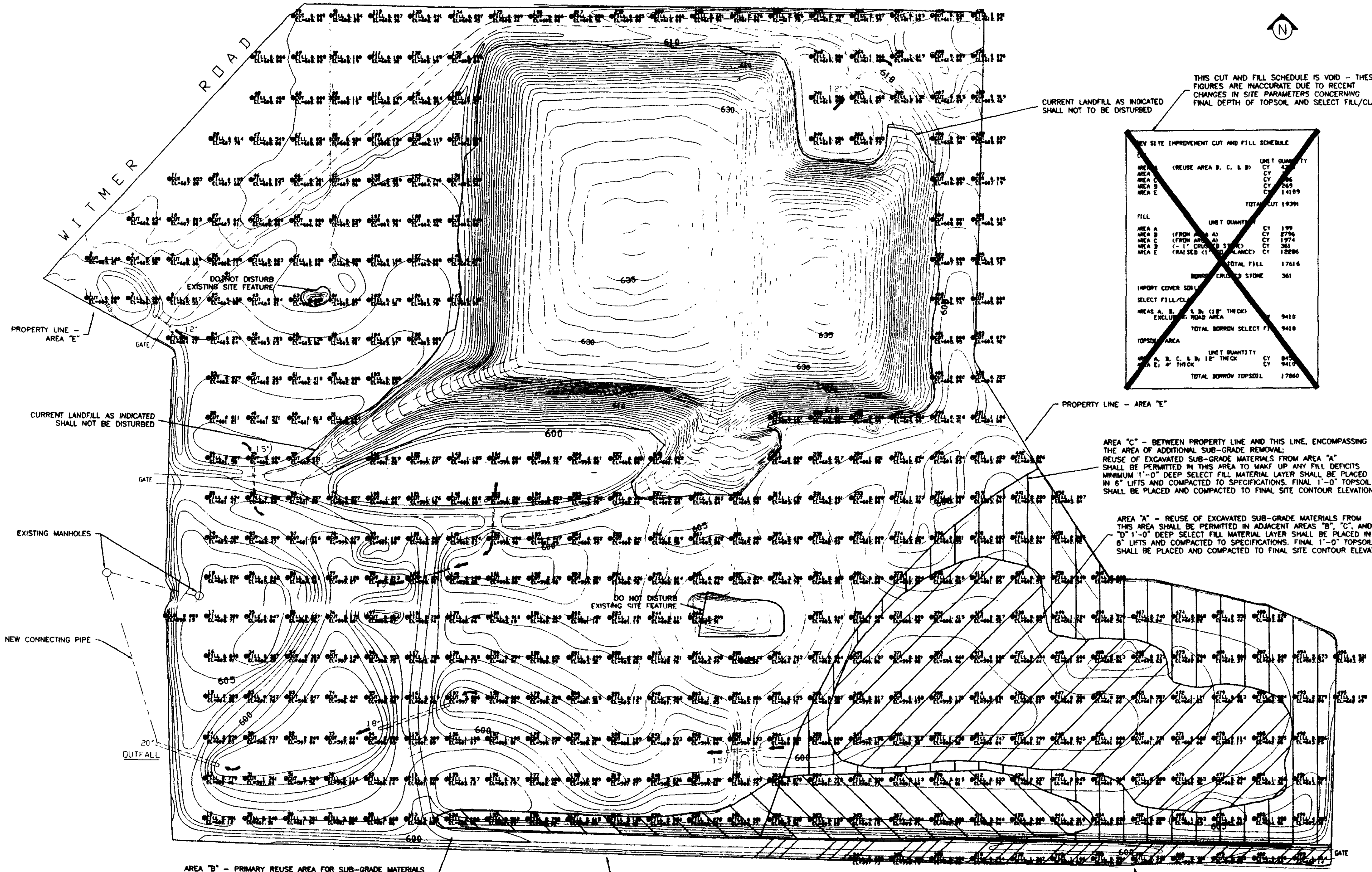
Return to Level Three Directory

Return to Macrogalleria Directory

8

Attachment 8

Site Plan
Grade Stake Layout 5



THIS CUT AND FILL SCHEDULE IS VOID - THESE FIGURES ARE INACCURATE DUE TO RECENT CHANGES IN SITE PARAMETERS CONCERNING FINAL DEPTH OF TOPSOIL AND SELECT FILL/CLAY

~~[illegible]EV SITE IMPROVEMENT CUT AND FILL SCHEDULE~~

~~C[illegible]~~

		~~UNIT~~	~~QUAN[illegible]TY~~
~~ARE[illegible]~~	~~(REUSE AREA B, C, & D)~~	~~CY~~	~~43[illegible]~~
~~AREA [illegible]~~		~~CY~~	[illegible]
~~AREA C~~		~~CY~~	~~[illegible]06~~
~~AREA D~~		~~CY~~	~~269~~
~~AREA E~~		~~C[illegible]~~	~~14109~~
		~~TOTA[illegible] CUT~~	~~19391~~

~~FILL~~

		~~UNIT~~	~~QUANTI[illegible]~~
~~AREA A~~		~~CY~~	~~199~~
~~AREA B~~	~~(FROM A[illegible] A)~~	~~CY~~	~~2796~~
~~AREA C~~	~~(FROM AR[illegible] A)~~	~~CY~~	~~1974~~
~~AREA D~~	~~(- 1" CRUS[illegible]D ST[illegible])~~	~~CY~~	~~361~~
~~AREA E~~	~~(RAISED (1' [illegible]LANCE)~~	~~CY~~	~~12206~~
		~~[illegible]TOTAL FILL~~	~~17616~~
		~~BORR[illegible] CRUS[illegible]D STONE~~	~~361~~

~~IMPORT COVER SOI[illegible]~~

~~SELECT FILL/CL[illegible]~~

~~AREAS A, B, [illegible] & D; (18" THICK) EXCLU[illegible]G ROAD AREA~~		[illegible]	~~9410~~
	~~TOTAL BORROW SELECT F[illegible]~~		~~9410~~

~~TOPSO[illegible] AREA~~

		~~UNIT~~	~~QUANTITY~~
~~[illegible] A, B, C, & D; 12" THICK~~		~~CY~~	~~845[illegible]~~
~~[illegible]A E; 4" THICK~~		~~CY~~	~~9410~~
	~~TOTAL BORROW TOPSOIL~~		~~17860~~

AREA "C" - BETWEEN PROPERTY LINE AND THIS LINE, ENCOMPASSING THE AREA OF ADDITIONAL SUB-GRADE REMOVAL; REUSE OF EXCAVATED SUB-GRADE MATERIALS FROM AREA "A" SHALL BE PERMITTED IN THIS AREA TO MAKE UP ANY FILL DEFICITS MINIMUM 1'-0" DEEP SELECT FILL MATERIAL LAYER SHALL BE PLACED IN 6" LIFTS AND COMPACTED TO SPECIFICATIONS. FINAL 1'-0" TOPSOIL SHALL BE PLACED AND COMPACTED TO FINAL SITE CONTOUR ELEVATIONS.

AREA "A" - REUSE OF EXCAVATED SUB-GRADE MATERIALS FROM THIS AREA SHALL BE PERMITTED IN ADJACENT AREAS "B", "C", AND "D" 1'-0" DEEP SELECT FILL MATERIAL LAYER SHALL BE PLACED IN 6" LIFTS AND COMPACTED TO SPECIFICATIONS. FINAL 1'-0" TOPSOIL SHALL BE PLACED AND COMPACTED TO FINAL SITE CONTOUR ELEVATIONS.

AREA "B" - PRIMARY REUSE AREA FOR SUB-GRADE MATERIALS EXCAVATED FROM AREA "A" REUSE OF EXCAVATED SUB-GRADE MATERIALS FROM AREA "A" SHALL BE PERMITTED IN THIS AREA TO MAKE UP ANY FILL DEFICITS MINIMUM 1'-0" DEEP NEW SELECT FILL MATERIAL LAYER SHALL BE PLACED IN 6" LIFTS AND COMPACTED TO SPECIFICATIONS. FINAL 1'-0" NEW TOPSOIL SHALL BE PLACED AND COMPACTED TO FINAL SITE CONTOUR ELEVATIONS

AREA "D" - 1" CRUSHED STONE USED AS FILL AND ROAD BED MATERIAL THIS LOCATION ONLY. MINIMUM 4" DEEP STONE LAYER SHALL BE PLACED AND COMPACTED TO FINAL SITE CONTOUR ELEVATIONS.

SITE PLAN - DEPTH STAKE LAYOUT

SCALE: 0 50 100

Revised Destroy all previous copies

NOTE.
DRAWING BASED ON AERIAL PHOTOGRAPH BY LOCKWOOD MAPPING OF ROCHESTER, NY
MARCH 17, 1996

Revisions
A REVISED NOTES AREAS A-E TJ 12//19/97
B VOID SCHEDULE TJ 05/19/98
C REMOVED PIPE TJ 07/08/98

Date	08/27/97
Checked	GVD
Drawn	T JONES
Scale	PLOT 1 60

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SKW METALS & ALLOYS, INC.
NIAGARA FALLS, NEW YORK

WITMER ROAD SITE- PROPERTY IMPROVEMENTS
DEPTH STAKE LAYOUT

GUY D. VAN DOREN, P.E.
LICENSE NO NY 57203

Dwg File No.	3269639
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