ME551/GEO551 Geology of Industrial Minerals Spring 2012

Commodities, Part 3

Chromite, Gypsum, helium, iodine, indium, iron ore, kyanite, manganese, perlite, nitrogen, phosphate, potash, salt, sulfur, pumice

Safety

Reminders

- Midterms
- April 13 NMGS Spring Meeting
- April 14 Field trip
- April 28 AIPG meeting and Field trip in afternoon (perlite mine or carbonatites)
- Commodity presentation in April
- Research Projects presentations April 30
- Finals, Project written report due May 4
- No class May 7

Chromite

Chromite

- chromite ore
- chromium chemicals
- chromium ferroalloys
- chromium metal
- $FeCr_2O_4$—contains chromium and iron oxide

Table 1. Minerals of spinel structure

Series	Elemental Basis	Mineral Name	Chemical Composition
Chromite	Chromium	Chromite	$FeCr_2O_4$
		Magnesiochromite*	$MgCr_2O_4$
Spinel	Aluminum	Spinel	$MgAl_2O_4$
		Hercynite	$FeAl_2O_4$
		Gahnite	$ZnAl_2O_4$
		Galaxite	$MnAl_2O_4$
Magnetite	Iron	Magnetite	$FeFe_2O_4$
		Magnesioferrite	$MgFe_2O_4$
		Franklinite	$ZnFe_2O_4$
		Jacobsite	$MnFe_2O_4$
		Trevorite	$NiFe_2O_4$

* Also called picrochromite.

Chromite—properties

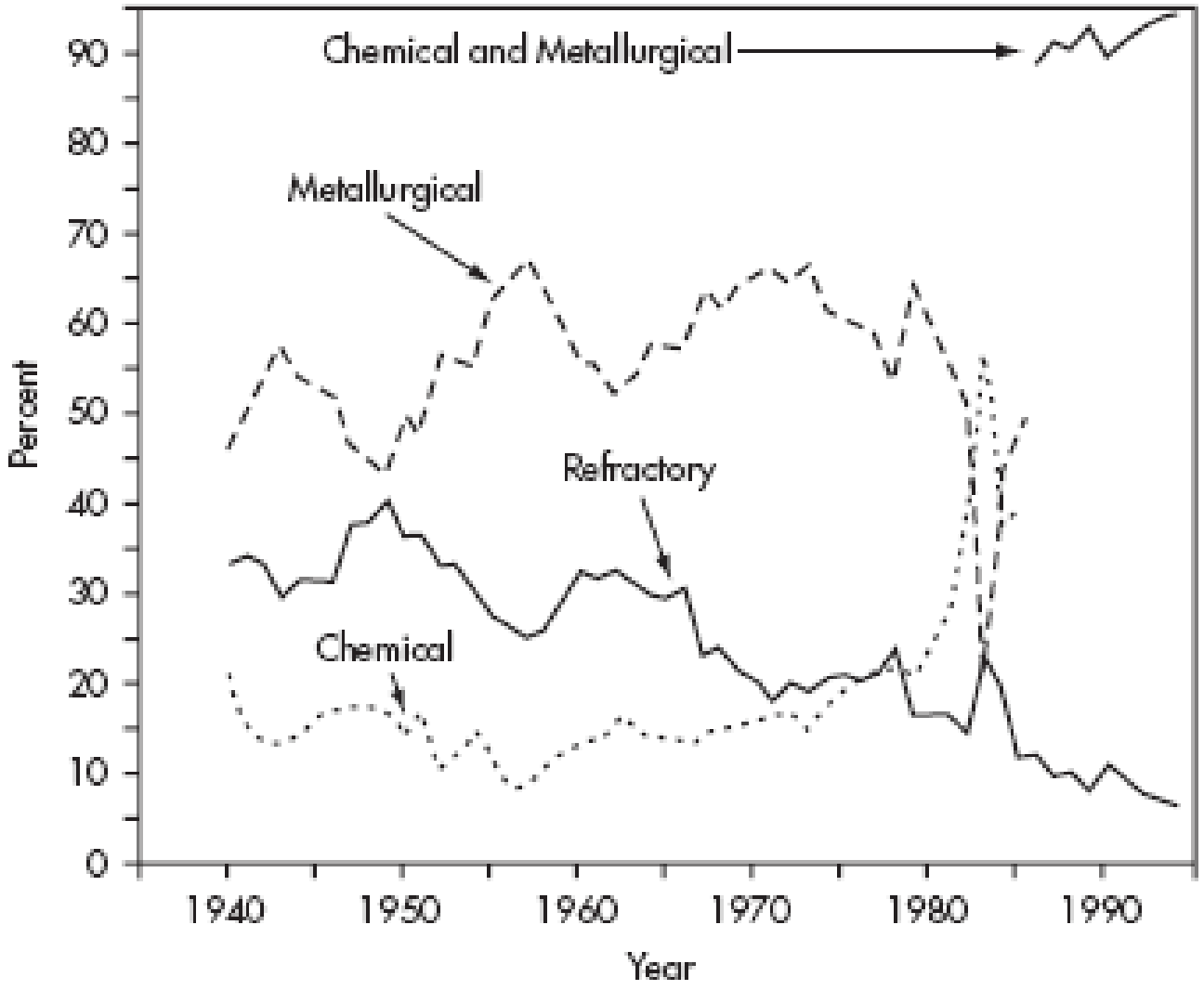
- Form alloys
- High melting and boiling points and densities because the electrons in the d orbitals, bind atoms together in the crystal lattice
- Form salts and other compounds

Chromite—uses

- Chemical industry (metal finishing, plating, corrosion control)
- Stainless steel
- Heat-resisting steel
- Superalloys
- Ferrous (cast iron and stainless steel)
- Nonferrous (aluminum, copper, and nickel) alloy metal fabrication
- Pigments and tanning compounds, and wood preservatives

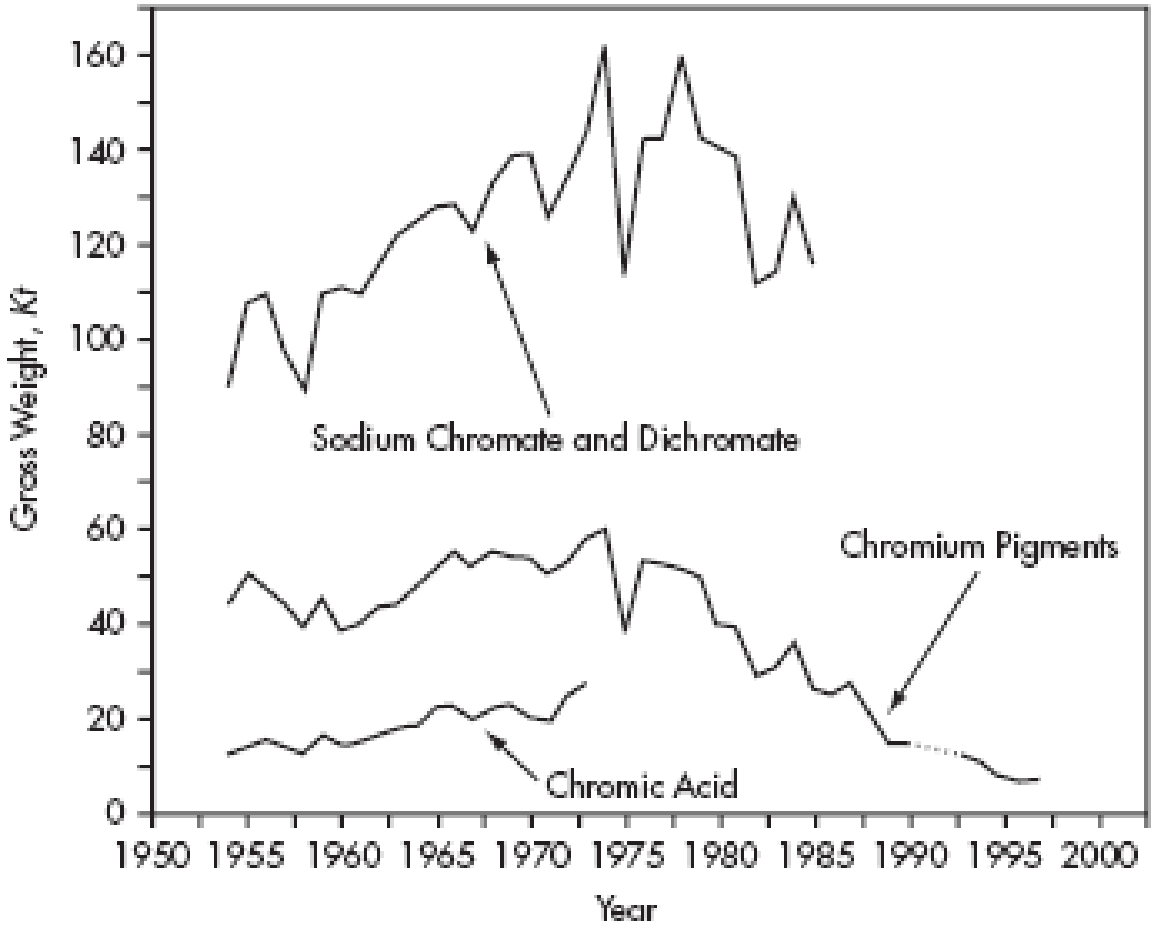
School bus yellow, originally called chrome yellow for the chromium pigment, was adopted for use on school buses in North America in 1939 because black lettering on the yellow buses is easy to see in the semidarkness of early morning.

https://pubs.usgs.gov/fs/2010/3089/pdf/fs2010-3089.pdf



Courtesy of USGS and U.S. Census Bureau.

Figure 7. U.S. chromite percent consumption by consuming industry (i.e., chemical, metallurgical, and refractory)



Courtesy of USGS and U.S. Census Bureau.

Figure 9. U.S. chromium chemical production by material (sodium chromate and sodium dichromate, chromic acid, and chromium-containing pigments). (The dotted line segment indicates linearly interpolated data.)

Chromite

- One U.S. company began mining chromite ore in Oregon in 2005-2006 but soon closed.
- This was the first U.S chromite ore mine production since 1961.
- Today all chromium is imported.
- It is listed as a critical mineral.

Salient Statistics—United States:	2013	2014	2015	2016	2017[e]
Production:					
Mine	—	—	—	—	—
Recycling[1]	150	157	161	170	160
Imports for consumption	557	683	511	528	600
Exports	240	256	236	253	250
Government stockpile releases	10	15	9	5	7
Consumption:					
Reported (includes recycling)	402	417	413	416	420
Apparent (includes recycling)[2]	477	598	445	451	510
Unit value, average annual import (dollars per ton):					
Chromite ore (gross weight)	309	243	216	198	320
Ferrochromium (chromium content)[3]	2,162	2,208	2,251	1,750	2,600
Chromium metal (gross weight)	11,147	11,002	11,235	9,926	9,500
Stocks, yearend, held by U.S. consumers	8	8	8	8	8
Net import reliance[4] as a percentage of apparent consumption	69	74	64	62	69

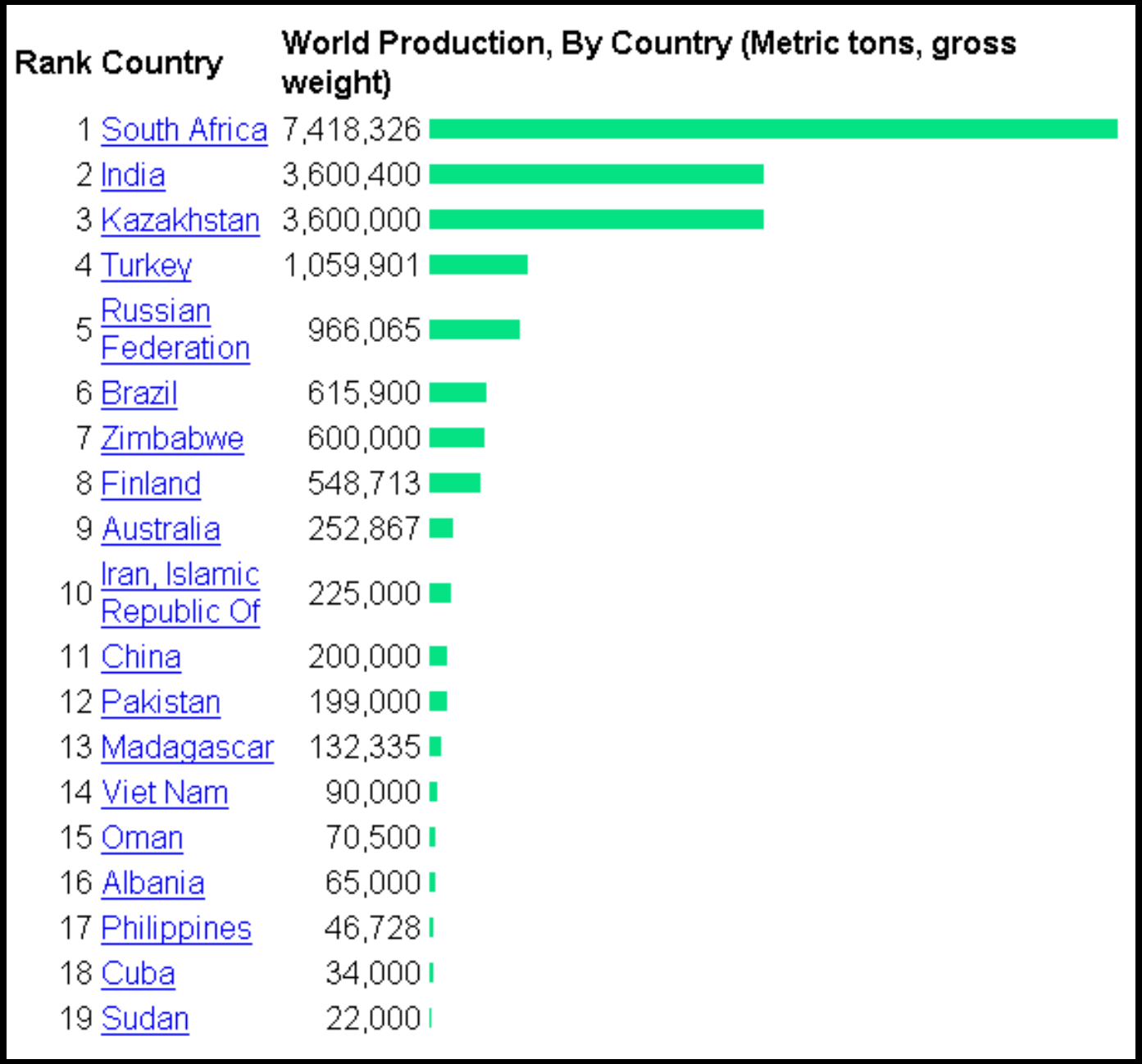
USGS Mineral Commodities Yearbook
Thousand metric tons

World Mine Production and Reserves: Reserves for Turkey were revised based on Government reports.

	Mine production[11]		Reserves[12] (shipping grade)[13]
	2016	2017[e]	
United States	—	—	620
India	3,200	3,200	54,000
Kazakhstan	5,380	5,400	230,000
South Africa	14,700	15,000	200,000
Turkey	2,800	2,800	26,000
Other countries	4,160	4,200	NA
World total (rounded)	30,200	31,000	510,000

World Resources: World resources are greater than 12 billion tons of shipping-grade chromite, sufficient to meet conceivable demand for centuries. The world's chromium resources are heavily geographically concentrated (95%) in Kazakhstan and southern Africa; United States chromium resources are mostly in the Stillwater Complex in Montana.

USGS Mineral Commodities Yearbook
Thousand metric tons



http://www.indexmundi.com/minerals/?product=chromite&graph=production

Geology

- Ultrmafic rocks—stratiform Mafic-Ultramafic Chromite Deposits
  - Dunite
  - Peridotite
  - Pyroxenite
  - Serpentine
- Podiform- or Alpine-Type Chromite Deposits
- Crude Oil (~100 ppm Cr), Tars and Pitch, Asphalts, and Coal (15-200 ppm)

Areas

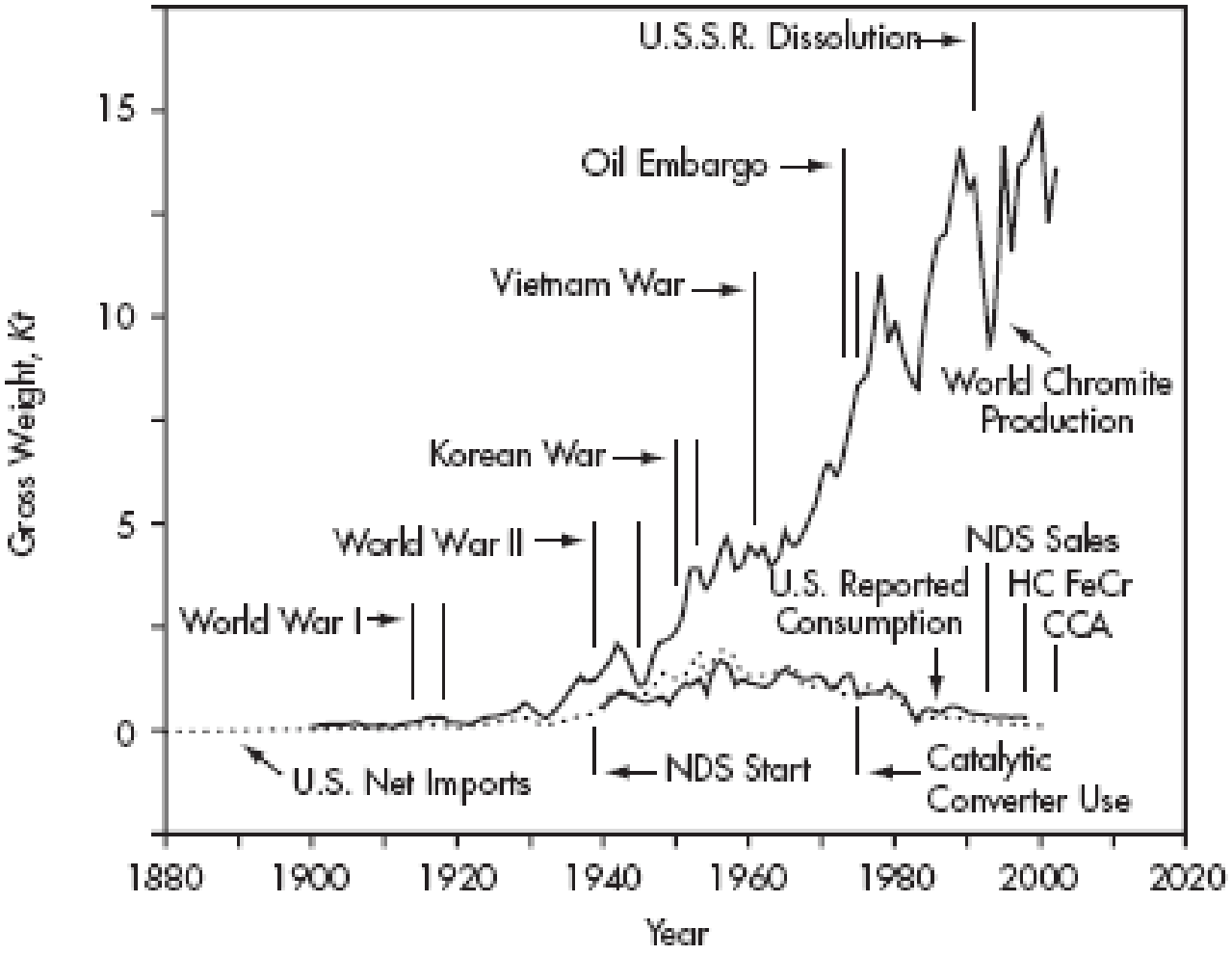
- South Africa
  - Bushveld complex layered igneous intrusion containing >11 billion metric tons of chromite
- Podiform deposits
  - layered igneous sequences that developed in oceanic crust below the sea floor
  - Pacific Coast from the Kenai Peninsula in southern Alaska to southern California
  - Appalachian Mountains from northern Vermont to Georgia

LEGEND: Geologic Deposit Type

Stratiform			Podiform			Laterite		
Symbol		Resources (Mt-Cr*)	Symbol		Resources (Mt-Cr*)	Symbol		Resources (Mt-Cr*)
Nonproducing	Producing		Nonproducing	Producing		Nonproducing	Producing	
○	●	>70	□	■	>70	None	None	>70
○	●	30–70	□	■	30–70	None	None	30–70
∘	•	<30	▫	▪	<30	△	▲	<30

*Million Tons Chromium

Figure 2. Location, geologic type, and size of major chromite ore deposits



Courtesy of USGS.

Figure 16. World chromite production and U.S. chromite reported consumption and net imports. U.S. net chromite imports are shown as a dotted line; reported chromite consumption, as a solid line.

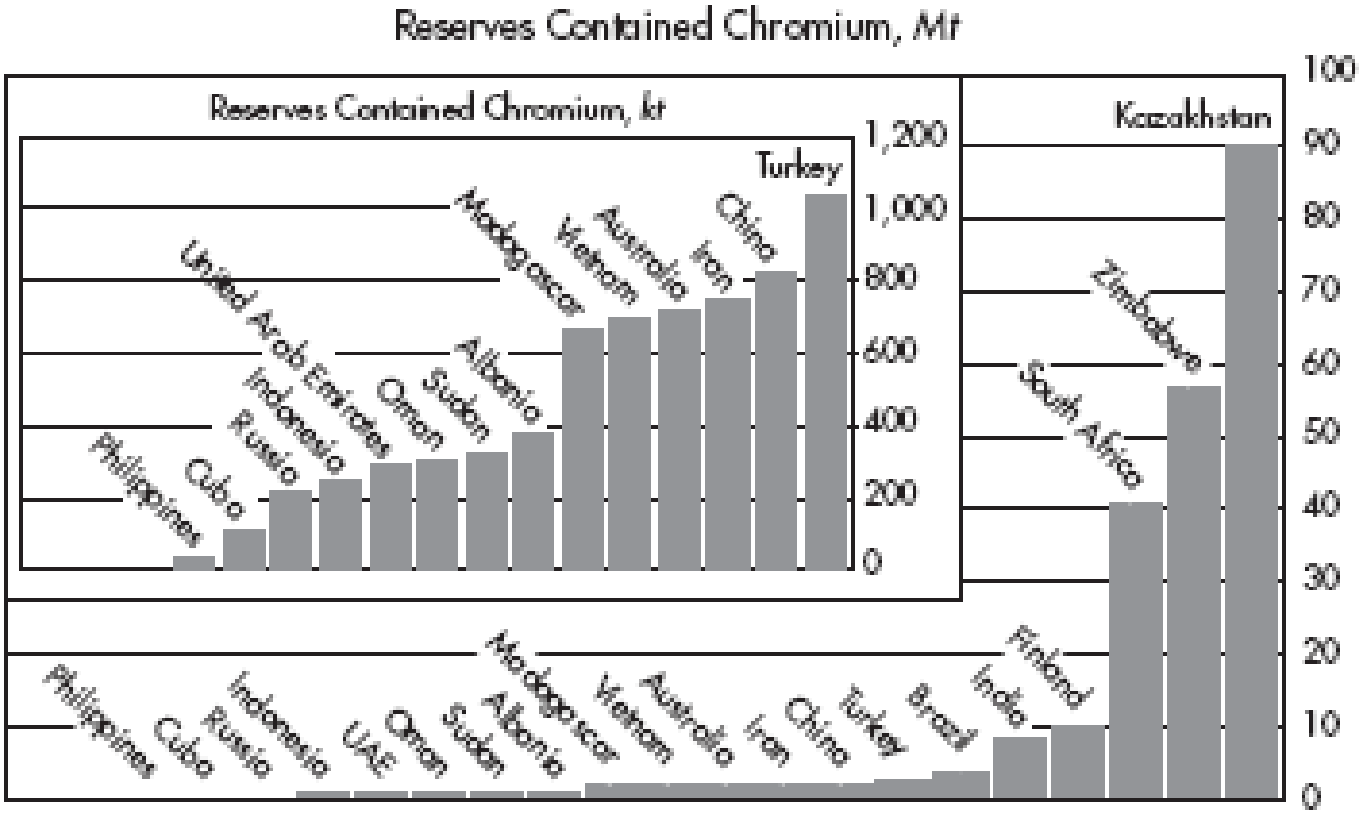


Figure 3. World chromite ore reserves by country. The bar chart shows countries with smaller reserves at a smaller scale so that their relative size is apparent.

Gypsum and anhydrite

The word gypsum is derived from the aorist form of the Greek verb μαγειρεύω, "to cook", referring to the burnt or calcined mineral.

Gypsum and anhydrite—introduction

- $CaSO_4 \cdot 2H_2O$
- commonest sulfate mineral
- heated, it loses 3/4 of its water and becomes hemihydrate gypsum ($CaSO_4 \cdot \frac{1}{2}H_2O$), or plaster of Paris
- minerals and rocks
- US world leader in trade

Gypsum and anhydrite—history

- Earliest known use of gypsum as a building material was in Anatolia around 6000 B.C.
- Great pyramids in Egypt, which were erected in about 3700 b.C
- Burning or calcining of gypsum was described by the early Greeks
- Gypsum mortar was used in medieval times in castles and fortresses in Germany

Differences

- Gypsum
  - lime 32.6% (CaO)
  - sulfur 46.5% (SO_3)
  - combined water 20.9% H_2O
- Anhydrite
  - lime 41.2% (CaO)
  - sulfur 58.8% (SO_3)
  - combined water 0% H_2O

Gypsum

http://209.51.193.54/minerals/sulfates/gypsum/gypsum.htm

http://en.wikipedia.org/wiki/Image:Desert-rose-big.jpg

Anhydrite

http://209.51.193.54/minerals/sulfates/gypsum/gypsum.htm

Types of gypsum

- **Gypsum,** $CaSO_4 \cdot 2H_2O$
- **Anhydrite,** $CaSO_4$
- **Bassanite,** $CaSO_4 \cdot \frac{1}{2}H_2O$ (phase)
- **Alabaster**, fine-grained rock gypsum
- **Satin spar**, deformed crystals
- **Selenite**, crystalline

Gypsum—properties

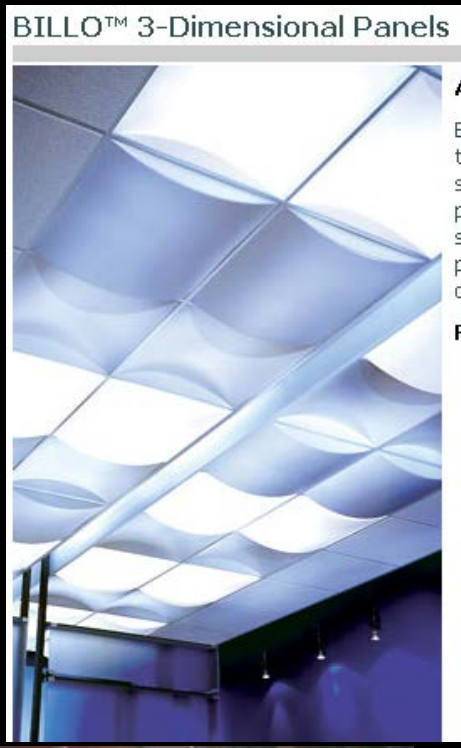
- Soft hardness 2
- White or colorless when pure, but can be tinted grayish, reddish, yellowish, bluish, or brownish
- Massive (alabaster)
- Fibrous (satin spar)
- Monoclinic crystals (selenite)

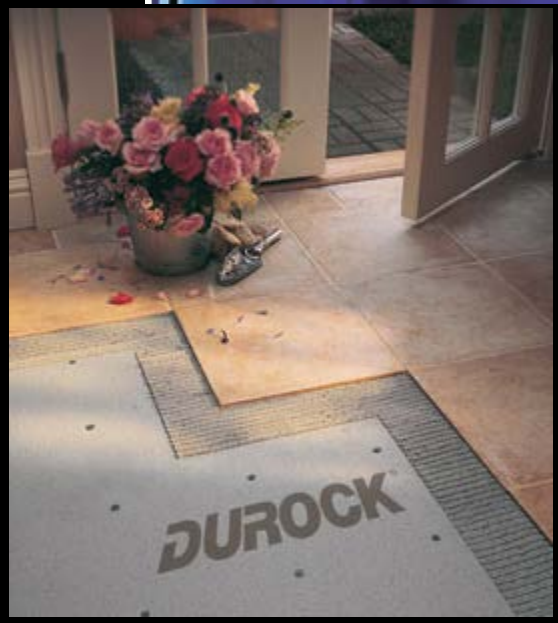
Gypsum—properties

- Luster is vitreous to pearly
- Crystal system is monoclinic
- Cleavage is good in one direction and distinct in two others
- Gravity is approximately 2.3+ (light)
- Very low thermal conductivity
- A crystal of gypsum will feel noticeably warmer than a like crystal of quartz.

Gypsum—uses

- Prefabricated wall board
- Industrial or building plaster
- Cement manufacturing
- Agriculture (fertilizer)
- Cements
- Paint filler
- Ornamental stone





Gypsum—uses

SALIENT GYPSUM STATISTICS[1]

(Thousand metric tons and thousand dollars)

	2011	2012	2013	2014	2015
United States:					
Crude:					
Production:					
Quantity	11,300 r	12,800 r	14,400 r	14,900 r	15,200
Value	92,000 r	98,100 r	128,000 r	132,000 r	135,000
Imports for consumption	3,330	3,250	3,290	3,720	4,030
Synthetic gypsum sales[2]	11,800	12,100	10,800	15,200	16,000
Calcined:					
Production:					
Quantity	11,900	12,800	14,600	14,700	15,000
Value	340,000	366,000	402,000	437,000	462,000
Products sold, value	1,470,000	2,230,000	2,940,000	3,090,000	3,240,000
Exports, value	48,300	39,200	44,100	46,000 r	42,100
Imports for consumption, value	7,780	7,150	5,830	7,620	7,210
World, production	241,000 r	243,000 r	252,000 r	261,000 r	261,000 e

eEstimated. rRevised.

[1]Data are rounded to no more than three significant digits.

[2]Source: American Coal Ash Association.

USGS Mineral Commodities Yearbook
Thousand metric tons

An average new American home of 2,000-square-foot floor area

- uses approximately 7.31 metric tons (t) of gypsum
- in more than 571 square meters (6,144 square feet) of gypsum wallboard

As a filler in food products

- the average person eats about 28 pounds of gypsum in a lifetime (National Gypsum Company, 2005)

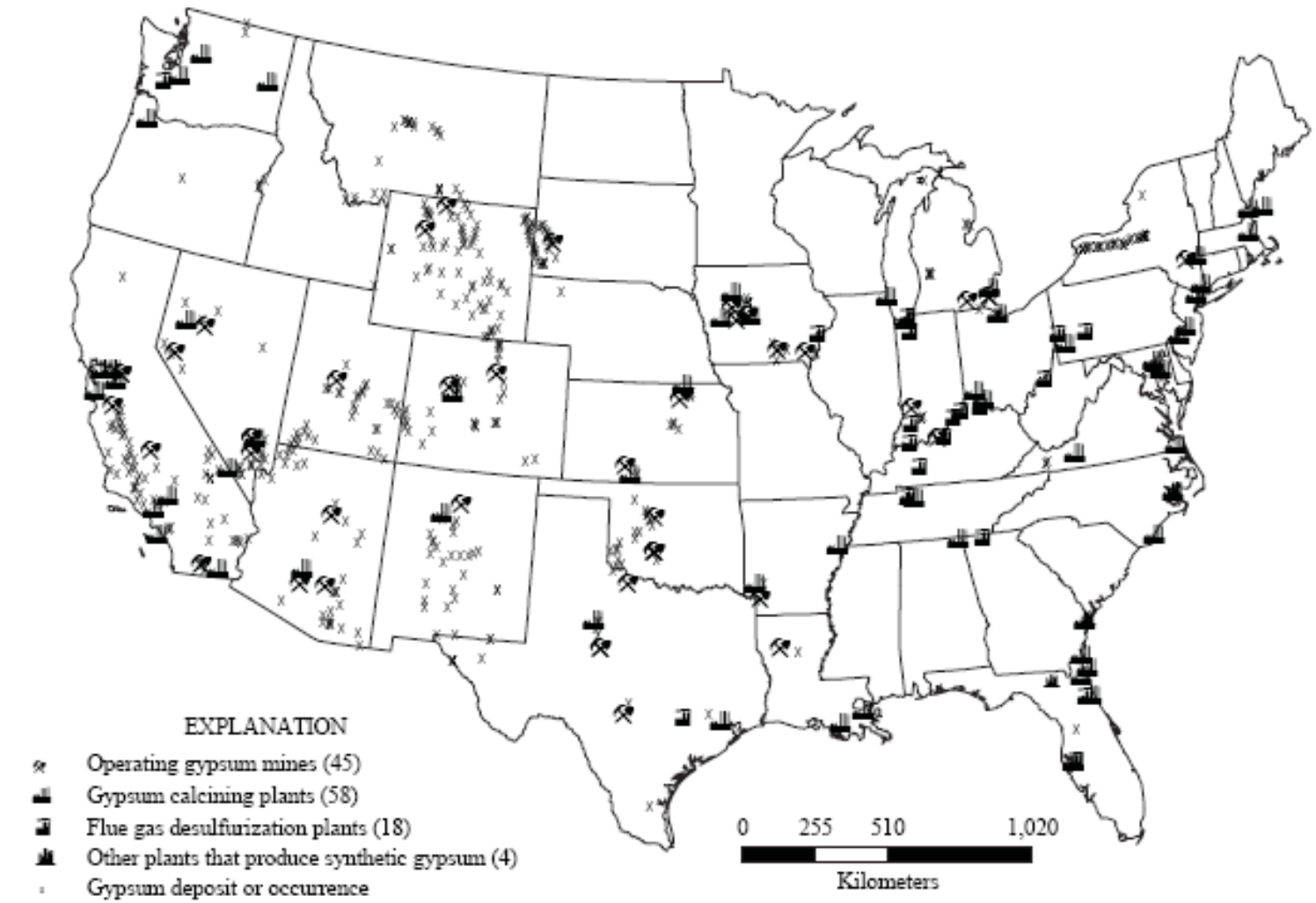
Gypsum—substitutions

- cement
- lime
- lumber
- masonry
- steel
- no practical substitute in the manufacturing of Portland cement

Gypsum—geology

- sedimentary
- massive beds, usually from precipitation of of highly saline waters

FIGURE 1
GYPSUM MINES, PLANTS, AND OCCURRENCES IN THE CONTERMINOUS UNITED STATES IN 2005



Sources: USGS survey, 2005; Withington, C.F., 1962, Gypsum and anhydrite in the United States (exclusive of Alaska and Hawaii): U.S. Geological Survey Minerals Investigation Resource Map MR-33, scale 1:3,168,000.

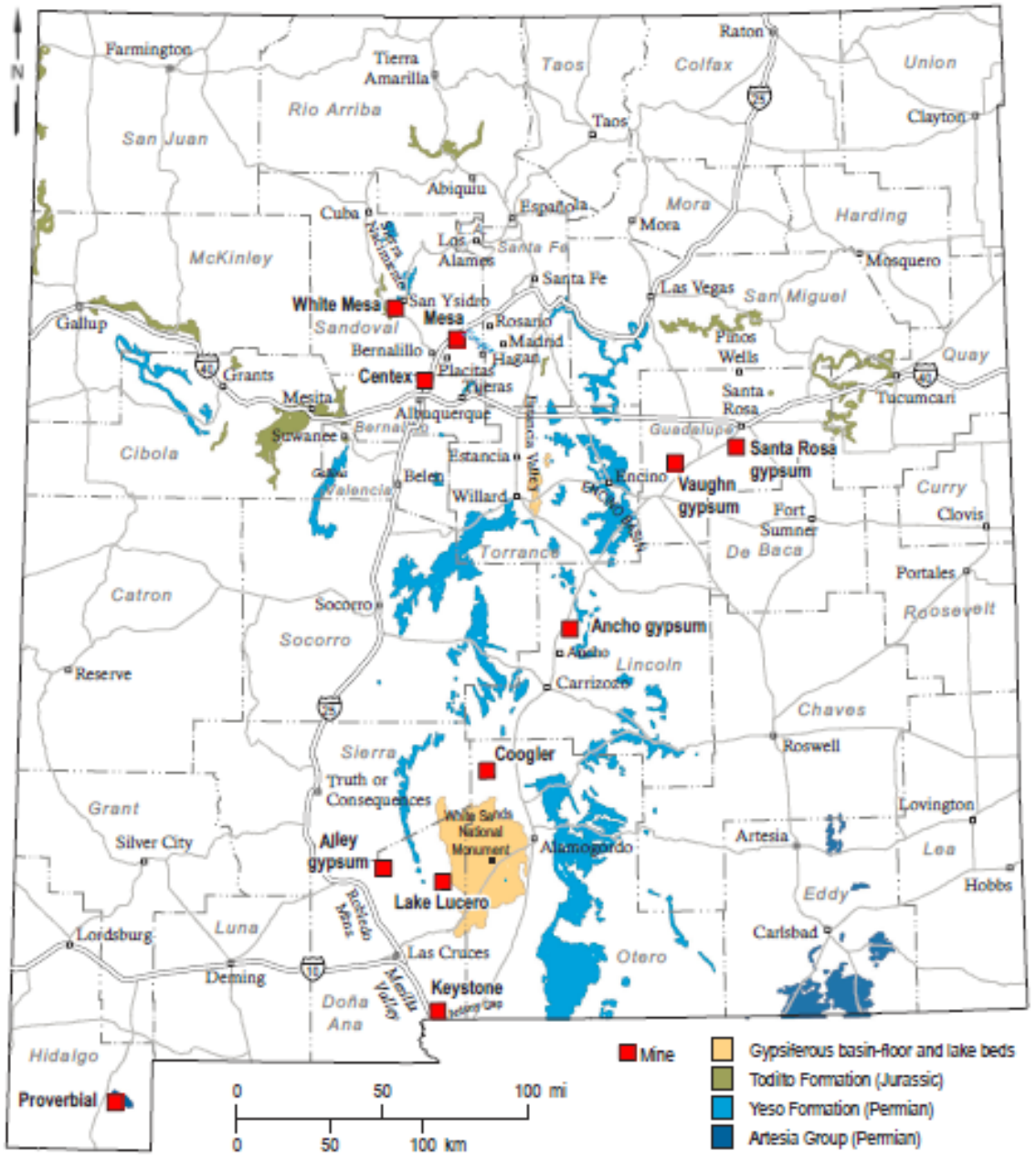


Figure 17. Major gypsum and anhydrite in New Mexico.

McLemore and Austin (2017)

Table 5. Worldwide distribution of principal gypsum resources

Geologic Age	North America	Europe	Asia	South America	Africa
Holocene	California	NA*	NA	NA	NA
Pleistocene	NA	NA	NA	NA	NA
Pliocene	NA	Greece	NA	NA	NA
Miocene	Nevada, California (Plaster City)	Bulgaria, Poland, Romania, Italy, Czech Republic, Slovakia	Saudi Arabia	NA	Egypt, Sudan
Oligocene	NA	Spain	NA	NA	NA
Eocene	NA	Romania	NA	NA	NA
Paleocene	NA	NA	NA	NA	NA
Cretaceous	Texas, Arkansas	NA	Laos	Brazil, Venezuela	NA
Jurassic	Iowa (Ft. Dodge), New Mexico, Colorado, Utah, Wyoming, Montana	England	NA	NA	Morocco, Tanzania
Triassic	NA	France, Germany, England, Austria, Spain	NA	NA	Algeria
Permian	Texas, Oklahoma, Kansas, Colorado, Wyoming, Nevada, Arizona	England, Austria, Lithuania, Poland, Hungary	NA	NA	NA
Pennsylvanian	NA	NA	NA	NA	NA
Mississippian	Nova Scotia, Michigan, Indiana, Virginia	NA	NA	NA	NA
Devonian	Iowa	Latvia, Lithuania	NA	NA	NA
Silurian	New York, Ontario, Ohio	NA	NA	NA	NA

* NA – not applicable (In this case, meaning that there was no occurrence of gypsum during the associated age.)

Gypsum is mined at White Mesa, Sandoval County (Centex American Gypsum) and used to manufacture wallboard.

Utility and value depends upon

- Proximity to market
- Transportation
- Fuel and utilities
- Water

Gypsum—production

Salient Statistics—United States:	**2013**	**2014**	**2015**	**2016**	**2017[e]**
Production:					
Crude[2]	15,700	16,200	16,600	17,000	17,500
Synthetic[3]	10,800	15,200	16,000	16,500	16,000
Calcined[4]	15,200	15,300	15,600	17,100	17,500
Wallboard products sold (million square feet[1])	21,800	21,500	22,100	24,700	25,000
Imports, crude, including anhydrite	3,290	3,720	4,030	4,340	4,800
Exports, crude, not ground or calcined	142	67	63	42	34
Consumption, apparent[5]	29,700	35,000	36,500	37,800	38,300
Price:					
Average crude, f.o.b. mine, dollars per metric ton	7.50	8.00	7.80	8.00	8.20
Average calcined, f.o.b. plant, dollars per metric ton	25.00	27.00	28.00	30.00	31.00
Employment, mine and calcining plant, number[e]	4,500	4,500	4,500	4,500	4,500
Net import reliance[6] as a percentage of apparent consumption	12	11	11	11	12

USGS Mineral Commodities Yearbook
Thousand metric tons
Nevada, Oklahoma, Texas, Kansas, Iowa, Colorado, New Mexico

Gypsum—production

TABLE 2
CRUDE GYPSUM MINED IN THE UNITED STATES, BY STATE[1]

State	2014 Active mines	2014 Quantity (thousand metric tons)	2014 Value (thousands)	2015 Active mines	2015 Quantity (thousand metric tons)	2015 Value (thousands)
Arizona, Colorado, New Mexico	7	1,210	$10,900	6	1,040	$9,300
Nevada and Utah	6 r	W	W	9	2,110	25,200
Arkansas and Louisiana	2	W	W	2	W	W
California	5	689	6,030	4	690	5,930
Iowa and Indiana	5	1,410	12,500	4	995	8,550
Michigan	3	233	2,050	2	W	W
South Dakota and Wyoming	3	W	W	3	W	W
Kansas, Oklahoma, Texas	20	8,300 r	73,300 r	20	8,780	71,500
Total	51 r	14,900 r	132,000 r	50	15,200	135,000

rRevised. W Withheld to avoid disclosing company proprietary data; included in "Total."
[1]Data are rounded to no more than three significant digits; may not add to totals shown.

USGS Mineral Commodities Yearbook
Thousand metric tons

Gypsum—production

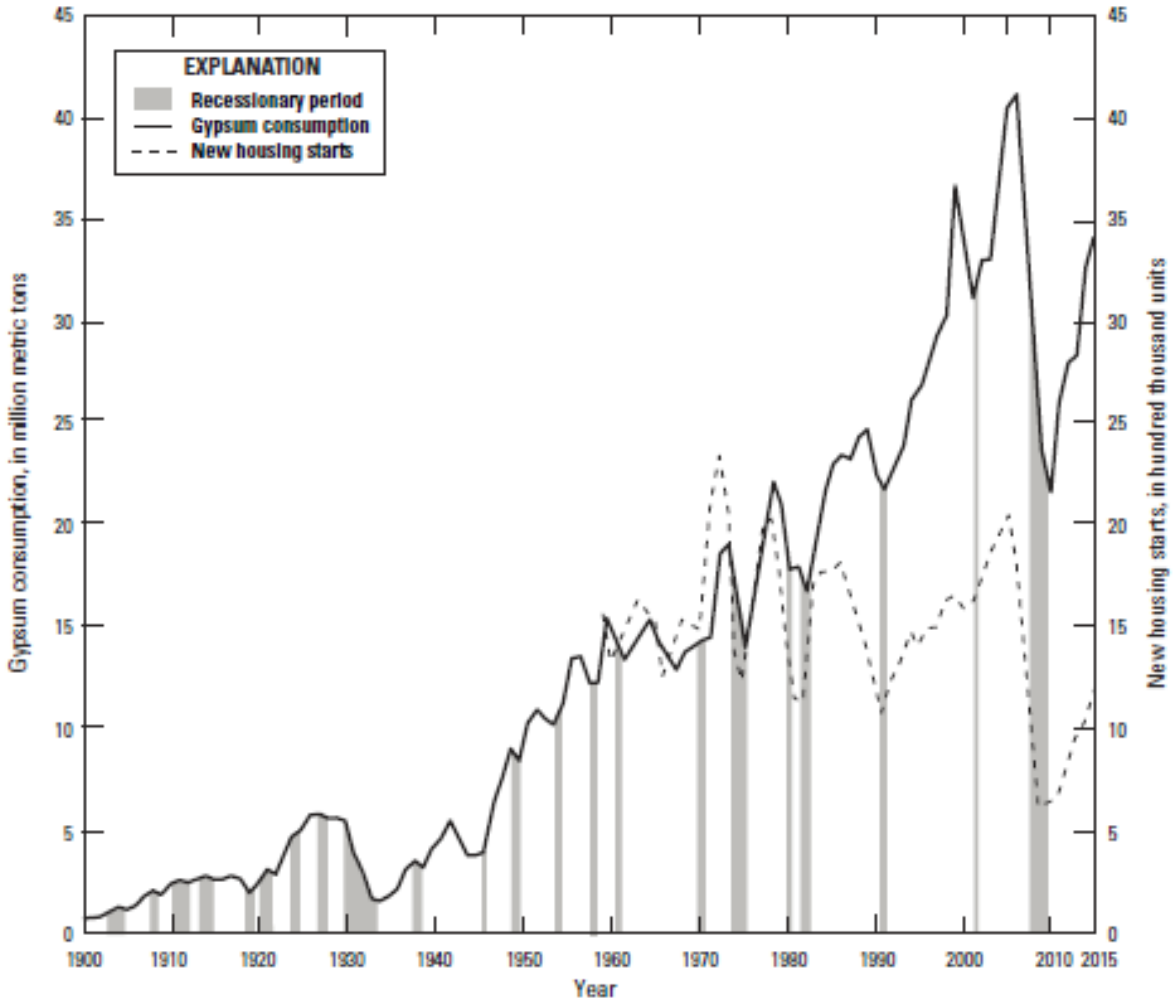


Figure 1. U.S. gypsum consumption and economic recessions from 1900 through 2015 and new residential building permits beginning in 1959. Sources: U.S. Census Bureau and U.S. Geological Survey.

USGS Mineral Commodities Yearbook
Thousand metric tons

Gypsum—products

TABLE 3
GYPSUM PRODUCTS (MADE FROM DOMESTIC, IMPORTED, AND SYNTHETIC GYPSUM) SOLD OR USED IN THE UNITED STATES, BY USE[1]

(Thousand metric tons and thousand dollars)

Use	2014		2015	
	Quantity	Value	Quantity	Value
Uncalcined:				
Portland and masonry cement	4,380 r	110,000 r	4,150	104,000
Agriculture and miscellaneous[2]	2,160 r	71,300 r	3,010	99,400
Total	6,540 r	181,000 r	7,160	203,000
Calcined:				
Plaster	80	34,300	80	35,100
Prefabricated products[3]	12,500	3,090,000	12,800	3,240,000
Total	12,500	3,120,000	12,900	3,270,000
Grand total	19,100 r	3,300,000 r	20,100	3,480,000

rRevised.
[1]Data are rounded to no more than three significant digits; may not add to totals shown.
[2]Includes synthetic gypsum.
[3]Includes weight of paper, metal, or other materials and some synthetic gypsum.

TABLE 7

GYPSUM: WORLD PRODUCTION, BY COUNTRY[1, 2]

(Thousand metric tons)

Country[3]	2011	2012	2013	2014	2015[e]
Algeria	1,610 [e]	1,958	2,078	2,130	2,130
Argentina	1,453	1,433	1,548 [r]	1,500 [e]	1,500
Australia[4]	2,220	2,120	2,270	2,580	2,580
Brazil	3,229	3,750	3,333	3,330 [e]	3,330
Canada[4]	2,449	1,832	1,837	1,811 [r]	1,633 [5]
Chile	918	799	1,015	843	843
China[4]	127,000	128,000	129,000	130,000	130,000
Egypt[6, 4]	2,138 [5]	2,200	2,200	2,200	2,200
France	4,231	3,685	3,455	3,279	3,280
Germany, marketable	2,021	1,949	1,778	1,802	1,800
India	3,114 [r]	3,337 [r]	3,189 [r]	3,902 [r]	3,500
Iran[6, 4]	15,353 [5]	14,179 [5]	15,800	16,000	16,000
Italy	5,939	2,563	2,994	8,551	8,550
Japan	4,770	5,002	4,771	4,674	4,670
Mexico[4]	3,560	4,693	5,091	5,496	5,378 [5]
Oman	1,254	1,915	2,785	4,210 [r]	6,049 [5]
Pakistan	1,131 [r]	1,173 [r]	1,753 [r]	1,436	1,660 [5]
Poland[4]	1,225	1,228	1,085	1,052	1,018 [5]
Russia	3,907	4,179	4,223	4,400 [e]	4,400
Saudi Arabia[4]	2,205 [5]	1,700	1,700	1,780	1,860
Spain[4]	7,826	6,360	7,125	7,000 [e]	7,000
Thailand	10,994	11,447	12,383	12,445	11,217 [5]
Turkey	8,894 [r]	11,442 [r]	13,357 [r]	12,618 [r]	12,600
United Kingdom[6, 4]	1,200	1,200	1,200	1,200	1,200
United States[7]	11,300 [r]	12,800 [r]	14,400 [r]	14,900 [r]	15,200 [5]
Other	11,400 [r]	12,300 [r]	11,900 [r]	12,300 [r]	11,800 [5]
Total	241,000 [r]	243,000 [r]	252,000 [r]	261,000 [r]	261,000

[e]Estimated. [r]Revised. -- Zero.

[1]Totals, U.S. data, and estimated data are rounded to no more than three significant digits; may not add to totals shown.

[2]Includes data available through February 23, 2017.

[3]In addition to the countries listed, Colombia, El Salvador, Honduras, Latvia, Luxembourg, Mongolia, and Serbia produced gypsum, but available information is inadequate to make reliable estimates of output levels.

[4]Includes anhydrite.

[5]Reported figure.

[6]Data are for years beginning March 21 of that stated.

[7]Does not include byproduct gypsum.

World Mine Production and Reserves: Reserves for Brazil, Turkey, and the United Kingdom were revised based on Government and industry information.

	Mine production		Reserves[7]
	2016	2017[e]	
United States	17,000	17,500	700,000
Algeria	2,130	2,100	NA
Argentina	1,500	1,500	NA
Australia	2,580	2,600	NA
Brazil	3,400	3,400	400,000
Canada	1,630	1,600	450,000
China	130,000	130,000	NA
Egypt	2,200	2,200	NA
France	3,280	3,300	NA
Germany	1,800	1,800	NA
India	3,500	3,500	39,000
Iran	16,000	16,000	1,600
Italy	8,550	8,600	NA
Japan	4,670	4,700	NA
Mexico	5,380	5,400	NA
Oman	6,050	6,000	4,900
Pakistan	1,660	1,700	NA
Russia	4,400	4,400	NA
Saudi Arabia	1,860	1,900	NA
Spain	7,000	7,000	NA
Thailand	11,300	11,000	NA
Turkey	9,000	9,000	170,000
United Kingdom	1,200	1,200	30,000
Other countries	15,000	15,000	NA
World total (rounded)	261,000	260,000	Large

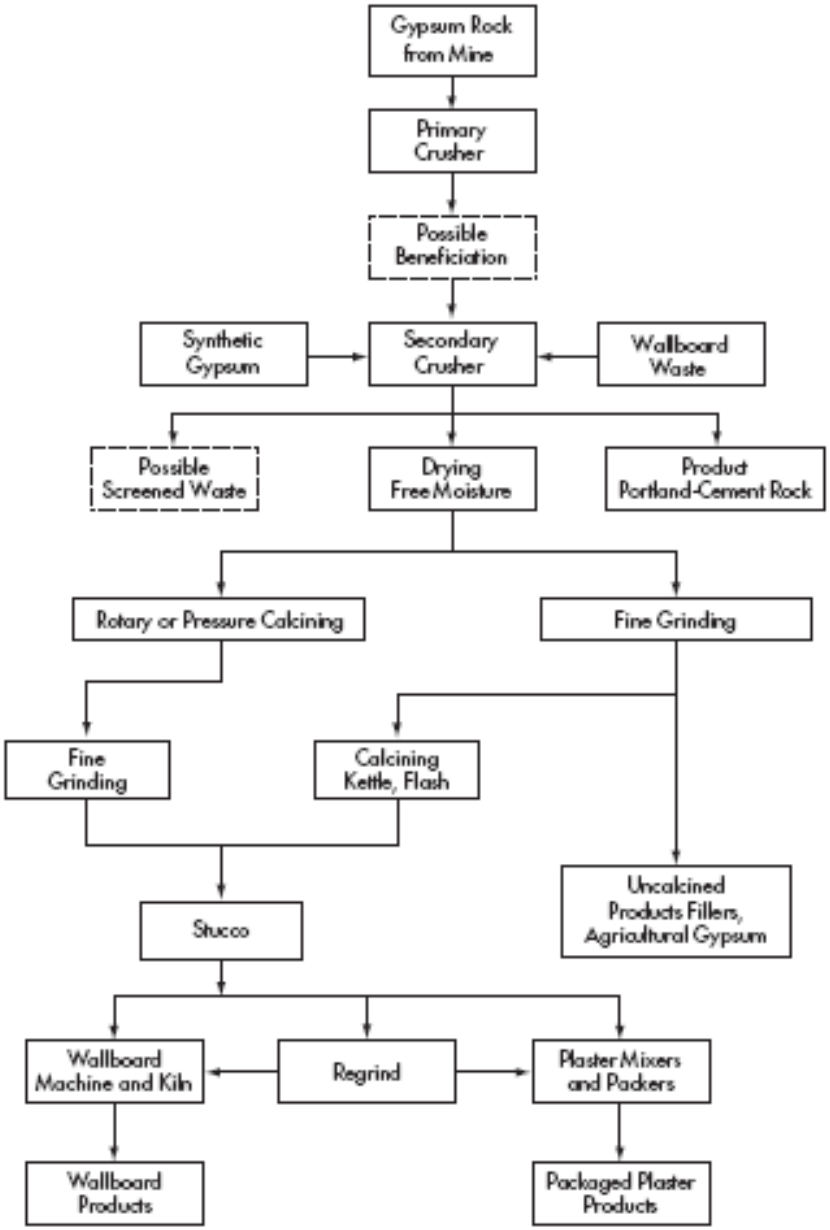


Figure 1. A general flow diagram of the manufacture of gypsum wallboard

Gypsum—prices

Table 6. Prices for gypsum by end use

End Use	Cost per Ton
Portland cement retarder	$12.37
Agricultural gypsum	$23.65
Wallboard	$87.02
Plasters	$150.98

Source: Olson 2002.

Helium

Helium—introduction

- He
- gas
- odorless
- colorless
- tasteless
- lighter than air
- critical mineral

Helium—uses

- Magnetic resonance imaging, 30%
- Lifting gas (cryogenic applications), 17%
  - DEA blimps
  - Advertising
- Analytical and laboratory applications, 14%
- Welding, 9%
- Engineering and scientific applications, 6%
- Leak detection and semiconductor manufacturing, 5% each
- Various other minor
- Applications, 14%.
- Hard drives

Helium—uses

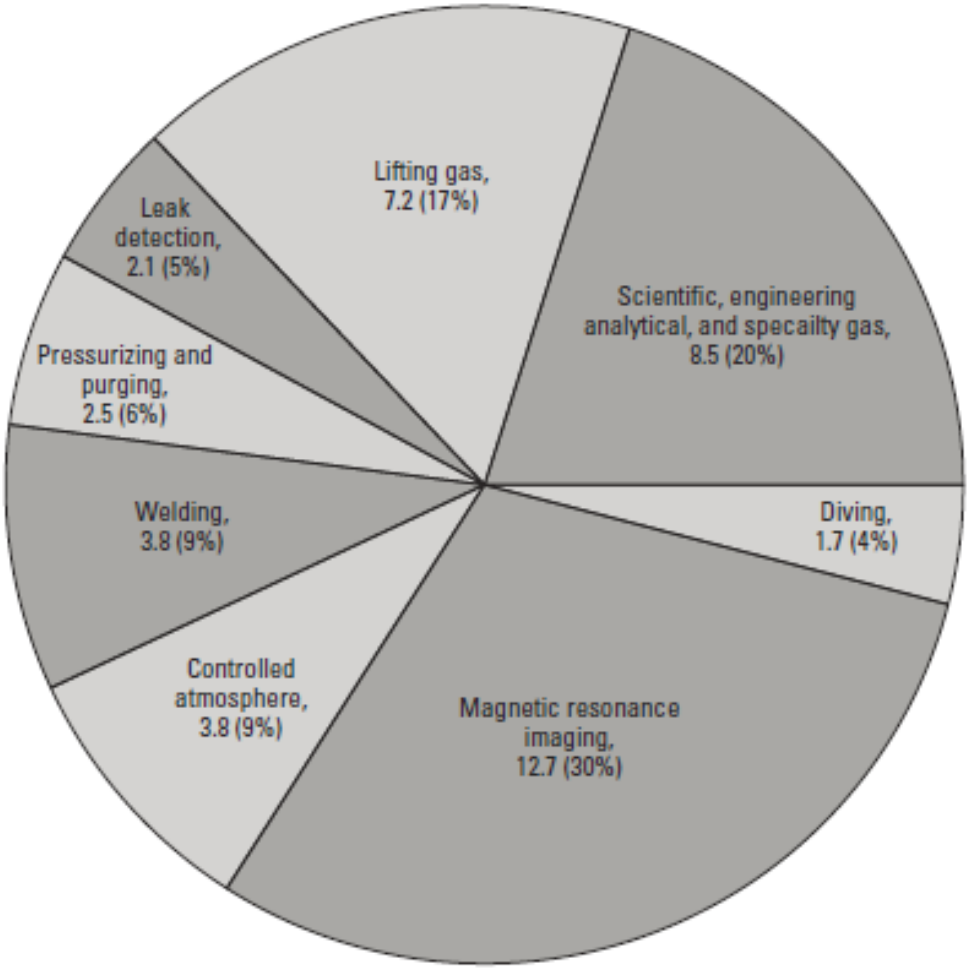


Figure 4. Estimated helium consumption in the United States in 2015, by end use, reported in million cubic meters. Total helium used in the United States in 2015 was estimated to be 42.3 million cubic meters.

Helium—substitutions

- Substituted for helium in cryogenic applications if temperatures below -429 degrees F are required
- Argon can be substituted for helium in welding
- H some lighter-than-air applications

Helium—geology

- Helium in the uranium mineral clevite
- 16 plants (Arizona, Colorado, Kansas, Oklahoma, Texas, Utah, Wyoming) extracted helium from natural gas and produced crude helium that ranged from 50% to 99% helium

Helium—production

Salient Statistics—United States:	2013	2014	2015[r]	2016	2017[e]
Helium extracted from natural gas[2]	69	75	71	66	63
Withdrawn from storage[3]	49	27	20	23	28
Grade-A helium sales	118	102	91	89	91
Imports for consumption	2	7	16	24	21
Exports[4]	81	67	65	61	69
Consumption, apparent[4]	39	42	42	52	43
Net import reliance[5] as a percentage of apparent consumption	E	E	E	E	E

million cubic meters of contained helium gas
USGS Mineral Commodities Yearbooks

Helium—production

World Production and Reserves:[8]

	Production		Reserves[9]
	2016	2017[e]	
United States (extracted from natural gas)	66	63	3,900
United States (from Cliffside Field)	23	28	([10])
Algeria	10	14	1,800
Australia	4	4	NA
Canada	<1	<1	NA
China	NA	NA	NA
Poland	2	2	25
Qatar	50	45	NA
Russia	3	3	1,700
World total (rounded)	160	160	NA

World Resources: Section 16 of Public Law 113-40 requires the U.S. Geological Survey (USGS) to complete a national helium gas assessment along with a global helium gas assessment. The USGS and the BLM have been coordinating efforts to complete this assessment. However, it may be several years before a project of this magnitude will be completed. The BLM plans to update the report of Helium Resources of the United States by yearend 2018. Until then, the following estimates are still the best available.

million cubic meters of contained helium gas
USGS Mineral Commodities Yearbooks

Helium—production

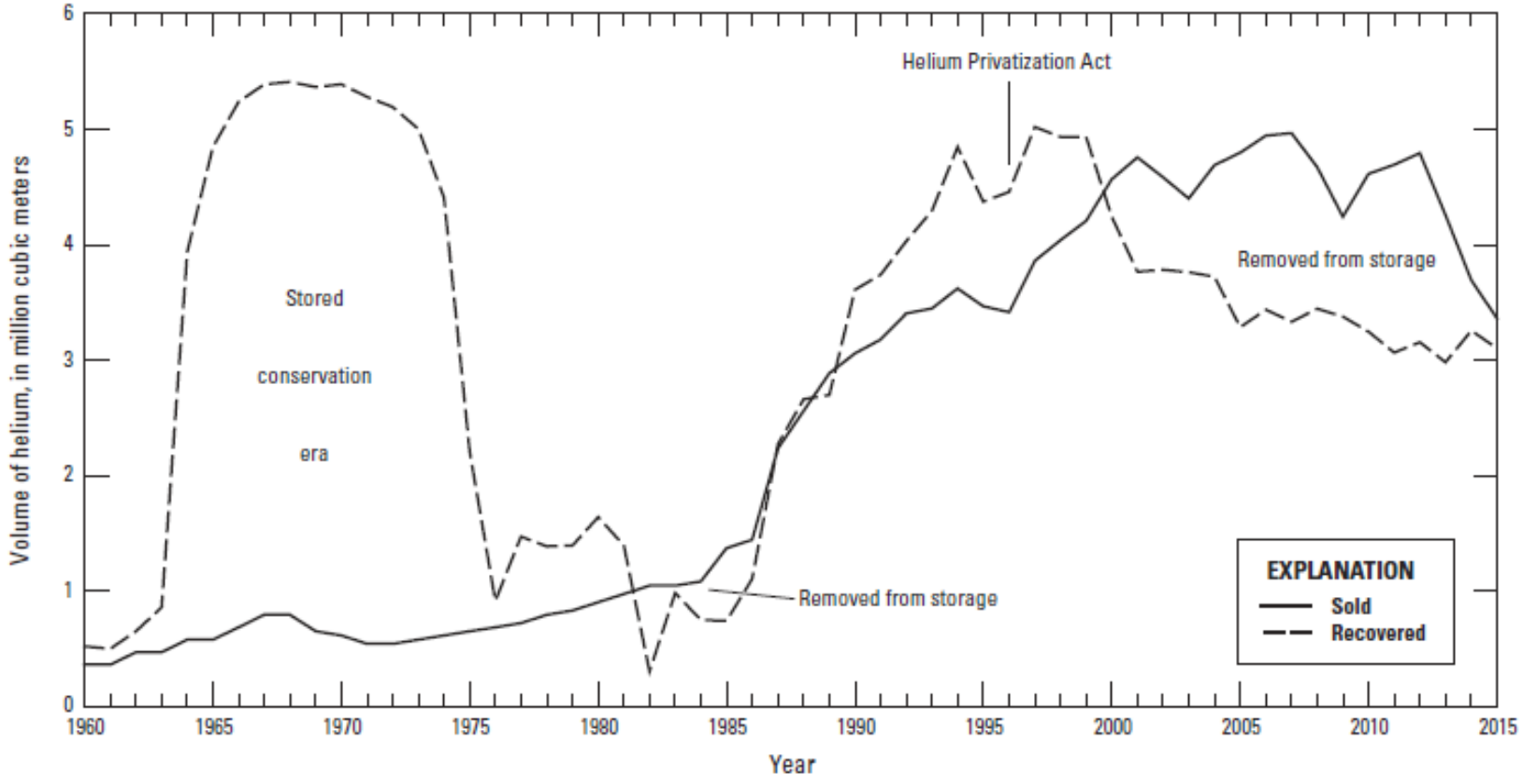


Figure 3. Helium recovery in the United States, 1960–2015.

TABLE 2

OWNERSHIP AND LOCATION OF HELIUM EXTRACTION PLANTS IN THE UNITED STATES IN 2015

Owner or operator	Plant name	Status	Location	Product purity
Air Products Corporation, Inc.	Liberal	Operating	Seward County, KS	Grade-A helium.[1]
Do.	Panhandle	Standby	Hansford County, TX	Do.[1]
Do.	Doe Canyon	Operating	Dolores County, CO	Do.[1]
DCP Midstream, LLC	Ladder Creek	do.	Cheyenne Wells, CO	Near-pure helium.[2]
Do.	National	do.	Seward County, KS	Crude helium.[3]
Do.	Rock Creek	do.	Hutchinson County, TX	Do.[3]
Do.	Sher-Han	do.	Hansford County, TX	Do.[3]
Denbury Onshore, LLC	Riley Ridge	Standby	Sublette County, WY	Do.[3]
Eagle Rock Energy	Sunray	Operating	Moore County, TX	Do.[3]
ExxonMobil Gas Marketing Co.	LaBarge	do.	Sweetwater County, WY	Grade-A helium.[1]
IACX Energy	Dineh-Bi-Keyah	do.	Apache County, AZ	Near-pure helium.[2]
Do.	Harley Dome	do.	Grand County, UT	Do.[2]
Do.	Hodgeman	do.	Hodgeman County, KS	Do.[2]
Do.	IACX Otis	do.	Rush County, KS	Do.[2]
Do.	Badger Wash	do.	Mesa County, CO	Do.[2]
Do.	Paden	do.	Okfuskee County, OK	Do.[2]
Do.	Woodside Dome	Under development	Emery County, UT	Do.[2]
Linde Global Helium, Inc.	Linde Otis	Operating	Rush County, KS	Grade-A helium.[1]
Linn Energy, LLC	Jayhawk	do.	Grant County, KS	Crude helium.[3]
Midstream Energy Services, LLC	Keyes	do.	Cimarron County, OK	Grade-A helium.[1]
Pioneer Natural Resources Co.	Fain	do.	Potter County, TX	Crude helium.[3]
Praxair, Inc.	Ulysses/Jayhawk	do.	Grant County, KS	Grade-A helium.[1]
Do.	Bushton	Standby	Ellsworth County, KS	Do.[1]

Do., do. Ditto.

[1]Including liquefaction, at least 99.99% helium.

[2]Generally contains between 95% and 98% helium.

[3]Generally contains between 60% and 80% helium.

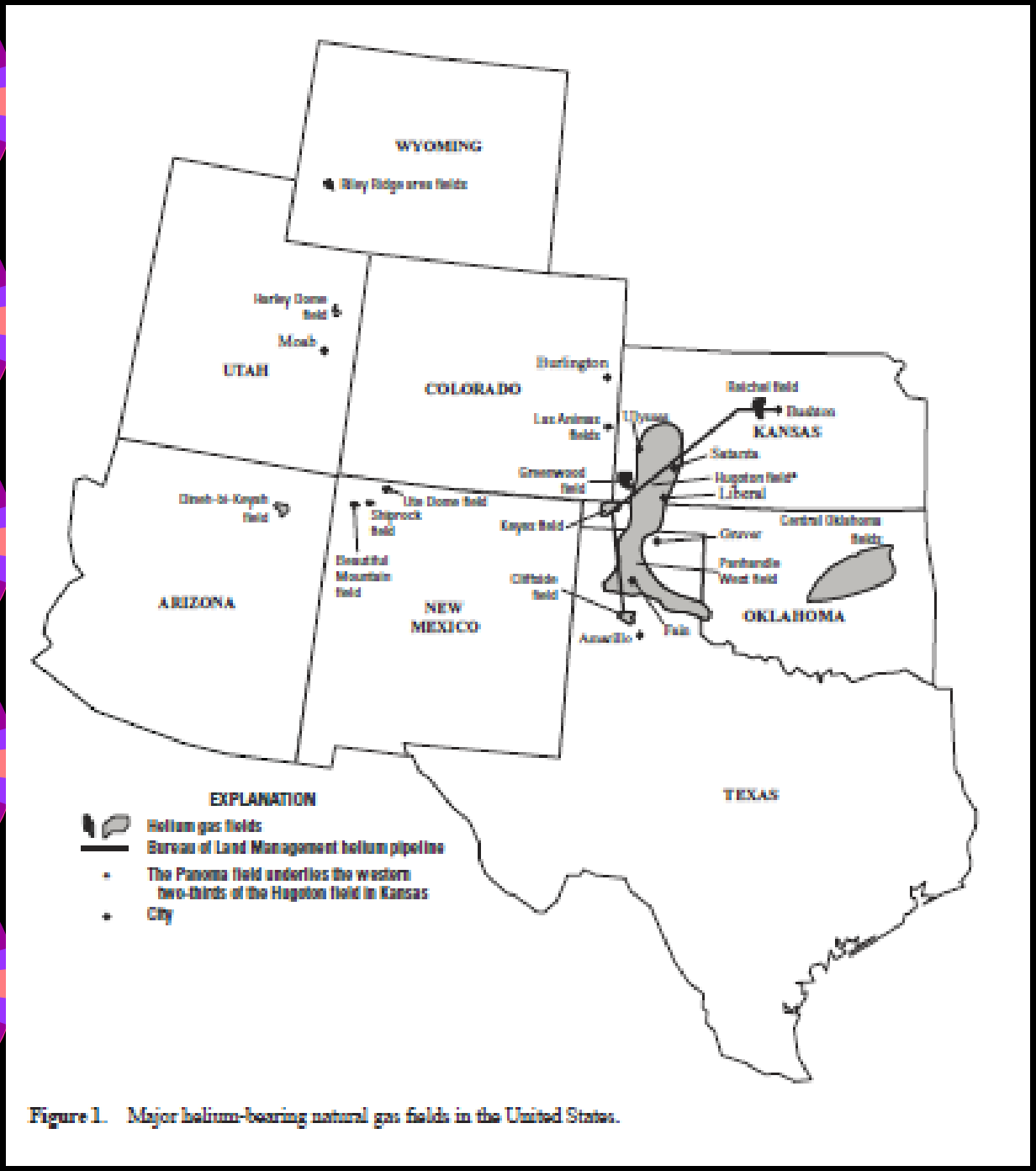


Figure 1. Major helium-bearing natural gas fields in the United States.

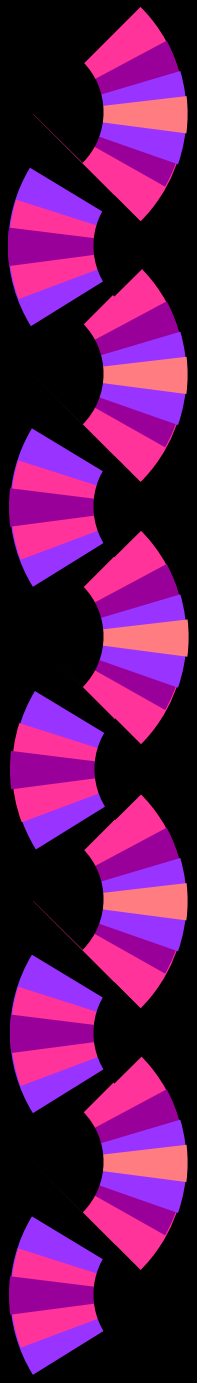
USGS Mineral Yearbooks

Table 2. Reservoirs and volumes provided by the USGS's Energy Resource Program, and helium concentrations provided by the Bureau of Land Management.

		Natural Gas (Billion m^3)	Avg Helium Content %	He (Billion m^3)
Alaskan North Slope	Shublik Shale Gas (2012)	1088	0.0111	0.121
Alaskan North Slope	Brookian Shale Gas (2012)	62	0.0111	0.007
Paradox Basin	Cane Creek Shale Gas	128	0.4150	0.532
Paradox Basin	Gothic, Chimney Rock, Hovenweep Shale Gas	184	0.4150	0.763
Denver Basin	Niobrara Chalk	28	0.0642	0.018
Permian Basin	Delaware-Pecos Basins Woodford	428	0.0282	0.121
Permian Basin	Delaware-Pecos Basins Barnett	487	0.0282	0.137
Permian Basin	Midland Basin Woodword-Barnett	80	0.0282	0.023
Bend Arch-Ft. Worth Basin	Greater Newark East Frac-Barrier Gas	415	0.2550	1.059
Bend Arch-Ft. Worth Basin	Extended Continuous Barnett Shale Gas	328	0.2550	0.836
Gulf Coast	Haynesville Sabine Platform Shale Gas	1720	0.0014	0.024
Gulf Coast	Mid-Bossier Sabine Platform Shale Gas	145	0.0014	0.002
Gulf Coast	Maverick Basin Pearsall Shale Gas	250	0.0014	0.003
Gulf Coast	Eagle Ford Shale Gas	1422	0.0014	0.020
Anadarko Basin	Woodford Shale Gas	452	0.2081	0.941
Anadarko Basin	Thirteen Finger LS-Atoka Shale Gas	194	0.2081	0.404
Arkoma Basin	Woodford Shale Gas	302	0.0110	0.033
Arkoma Basin	Chattanooga Shale Gas	46	0.0110	0.005
Arkoma Basin	Fayetteville-High Gamma Ray Depocenter	257	0.0110	0.028
Arkoma Basin	Fayetteville Western Arkansas Basin	118	0.0110	0.013
Arkoma Basin	Caney Shale Gas	32	0.0110	0.004
Michigan Basin	Devonian Antrim Continuous Gas	212	0.0371	0.079
Illinois Basin	Devonian-Mississippian New Albany Shale	107	0.0371	0.040
Appalachian Basin	Northwestern Ohio Shale	75	0.0497	0.037
Appalachian Basin	Devonian Siltstone and Shale	37	0.0497	0.018
Appalachian Basin	Foldbelt Marcellus (2011)	22	0.0497	0.011
Appalachian Basin	Interior Marcelllus (2011)	2305	0.0497	1.145
Appalachian Basin	Western Margin Marcellus (2011)	58	0.0497	0.029
Appalachian Basin	Utica Shale Gas (2012)	1056	0.0497	0.525
		12037		6.977

https://kb.osu.edu/dspace/bitstream/handle/1811/61504/phetteplace_thesissigned2014.pdf?sequence=3

Iodine



iode in French, from the Greek word *ioeides*, meaning violet-colored

Iodine—introduction

- Halogen
- Solid
- At least 24 minerals
  - bellingerite $Cu^{++}_3(IO_3)_6.2H_2O$
  - georgeericksenite $Na_6CaMg(IO_3)_6(CrO_4,SO_4)_2.12H_2O$
  - schwartzembergite $Pb^{++}_5I^{+++}O_6H_2Cl_3$

Iodine—properties

- Heavy, grayish-black crystalline solid
- Metallic luster
- Density of 4.9 g/cm3
- Halogen family
- Melts at 114°C
- At 184°C it will volatilize to a blue-violet gas that has an irritating odor


Crystalline iodine

Iodine—uses

- pharmaceutical and medical applications
  - methamphetamine (controlled substance)
  - radiation emergencies
- sanitation or disinfectants
- animal feed
- catalysts
- inks
- colorants
- photographic equipment
- stabilizers manufacturing of nylon
- cloud seeding
- quartz-iodine lights

In the gas phase, iodine shows its violet color.

IOSAT Potassium Iodide blocks the thyroid's absorption of cancer-causing radioactive iodine released from a nuclear reactor or nuclear bomb

Iodine—substitutions

- Bromine
- Chlorine
- Antibiotics
- Mercurochrome
- Salt crystals and finely divided carbon may be used for cloud seeding.
- No substitutes for iodine in some catalytic, nutritional, pharmaceutical, animal feed, and photographic uses.

Iodine—geology

- Chile, iodine is a coproduct of sodium nitrate production
- Brine in Oklahoma
- Japan and Oklahoma produced iodine from brines associated with natural gas production
- Seawater and brines
- Brackish waters from oil wells
- Iodides in sea water is assimilated by seaweeds
- 150-250 ppm in Permian Basin

TABLE 5

CRUDE IODINE: WORLD PRODUCTION, BY COUNTRY[1, 2]

(Metric tons)

Country[3]	2011	2012	2013	2014	2015
Azerbaijan	230	240	249	263 r	247
Chile	16,000	17,494	20,656	18,989 r	20,000 e
Indonesia	61	44	43	56 r	45
Japan	9,277	9,315	9,334	9,814 r	9,800 e
Russia[e]	210	200	--	--	--
Turkmenistan[e]	470	480	500	500	510
United States	W	W	W	W	W
Total[e, 4]	26,200	27,800	30,800	29,600 r	30,600

rRevised. W Withheld to avoid disclosing company proprietary data; not included in total. -- Zero.

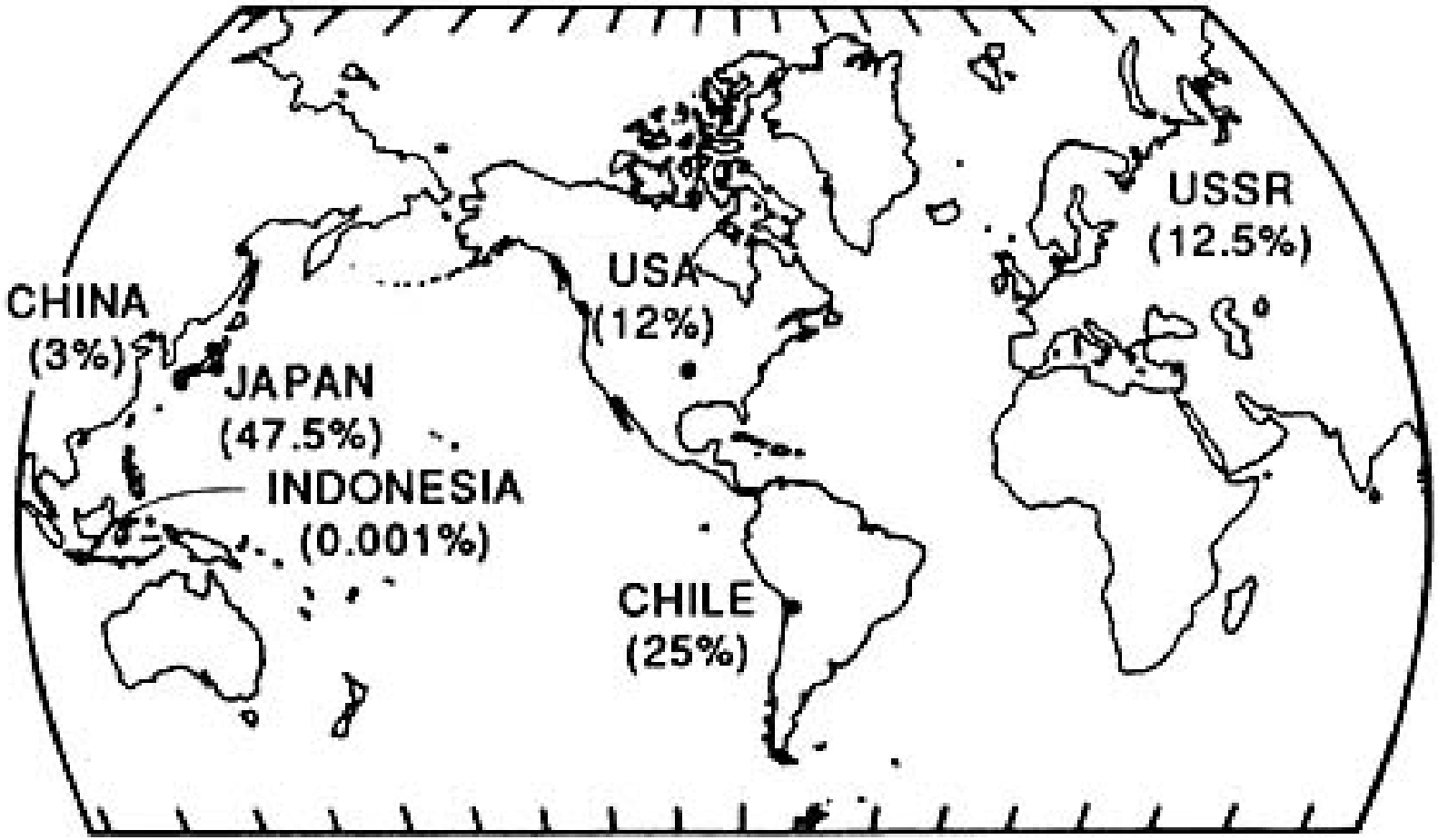
[1]World totals and estimated data are rounded to no more than three significant digits; may not add to totals shown.

[2]Includes data available through April 22, 2016.

[3]In addition to the countries listed, China and Iran also produce crude iodine, but output is not officially reported and available general information is inadequate for the formulation of reliable estimates of output levels.

[4]Does not include U.S. production.

Fig. 1. Countries producing iodine and percentage of estimated world production during 1990.



from Cotten, 1978.

2005

File:Iodine.PNG

From Wikipedia, the free encyclopedia

File | File history | File links

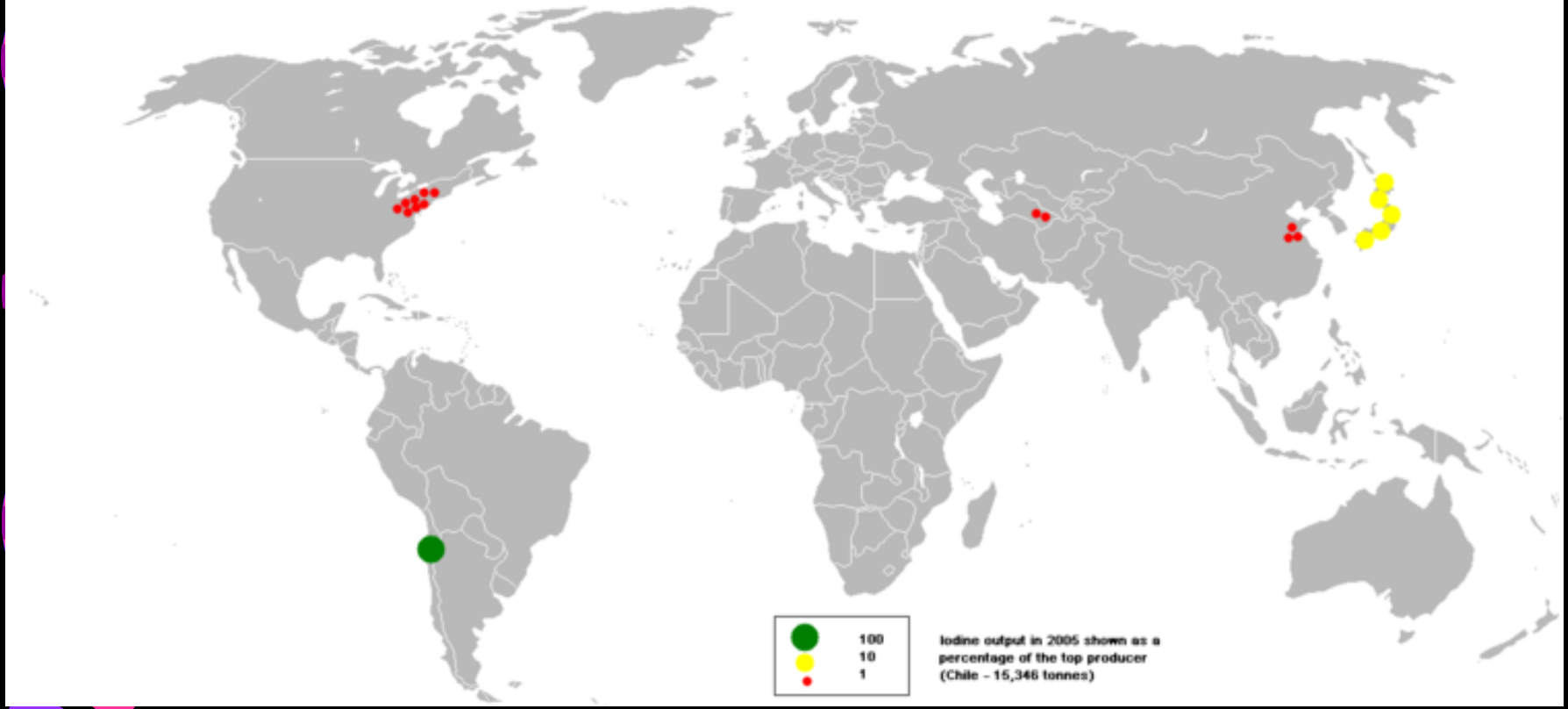
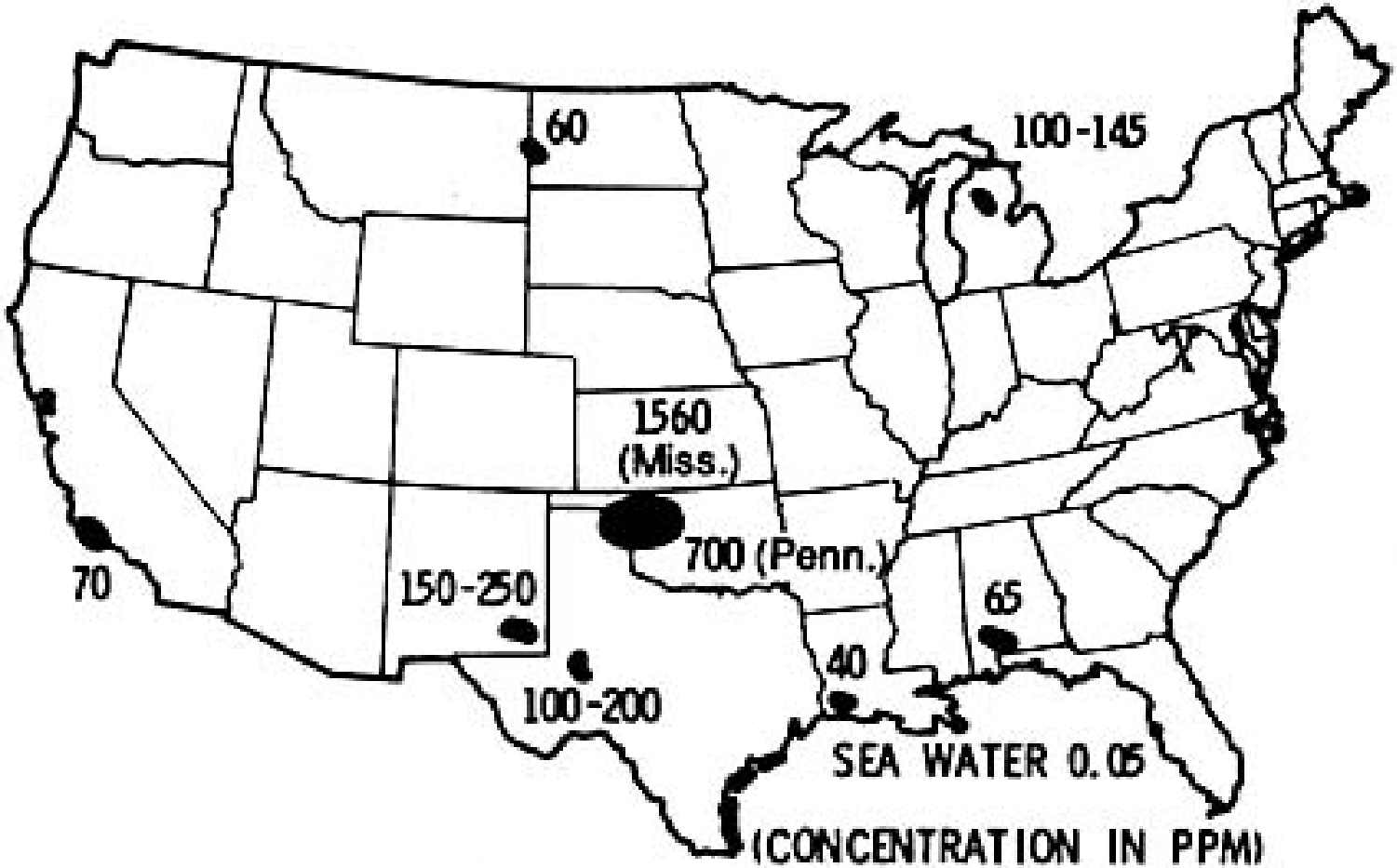
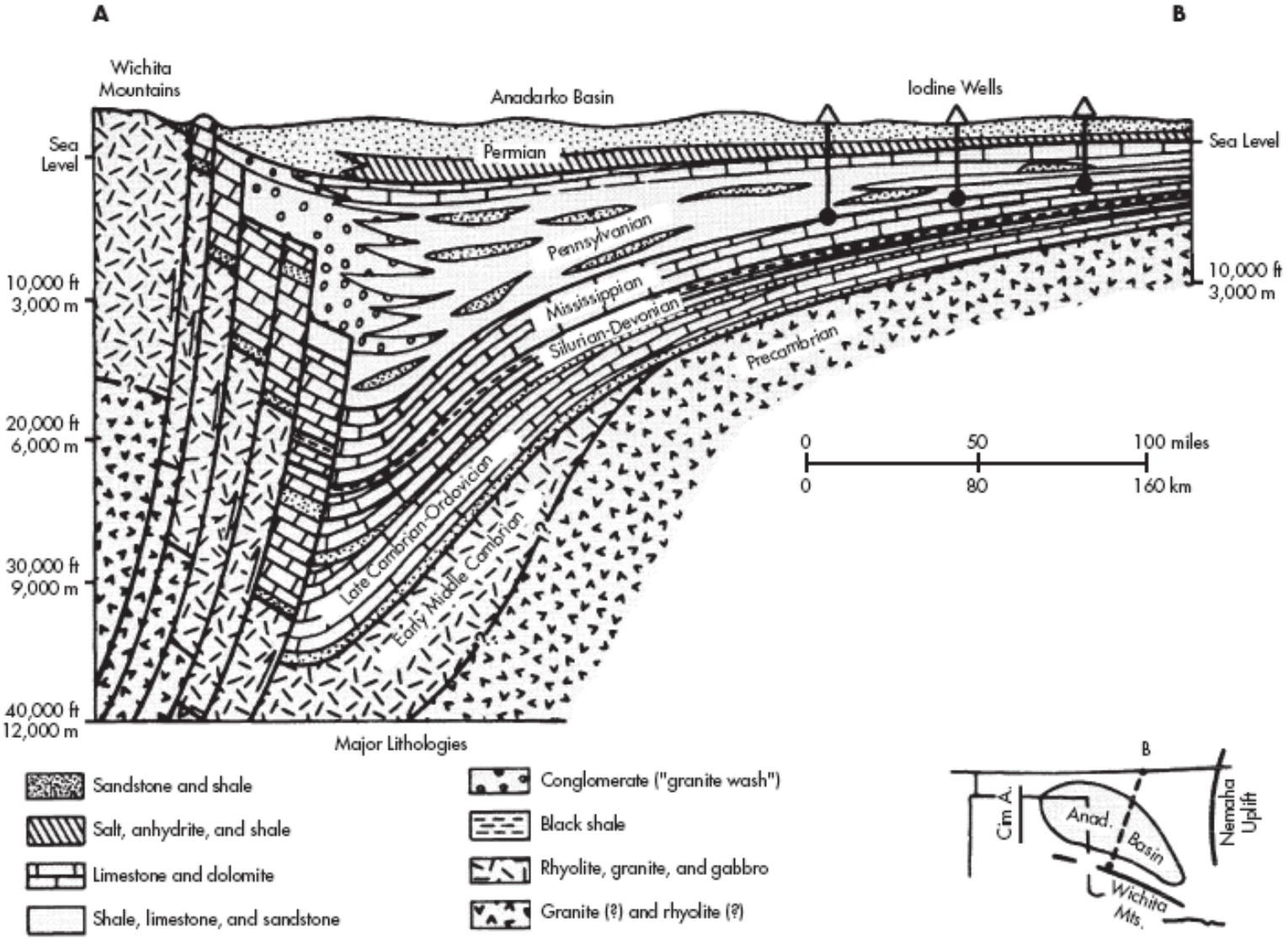


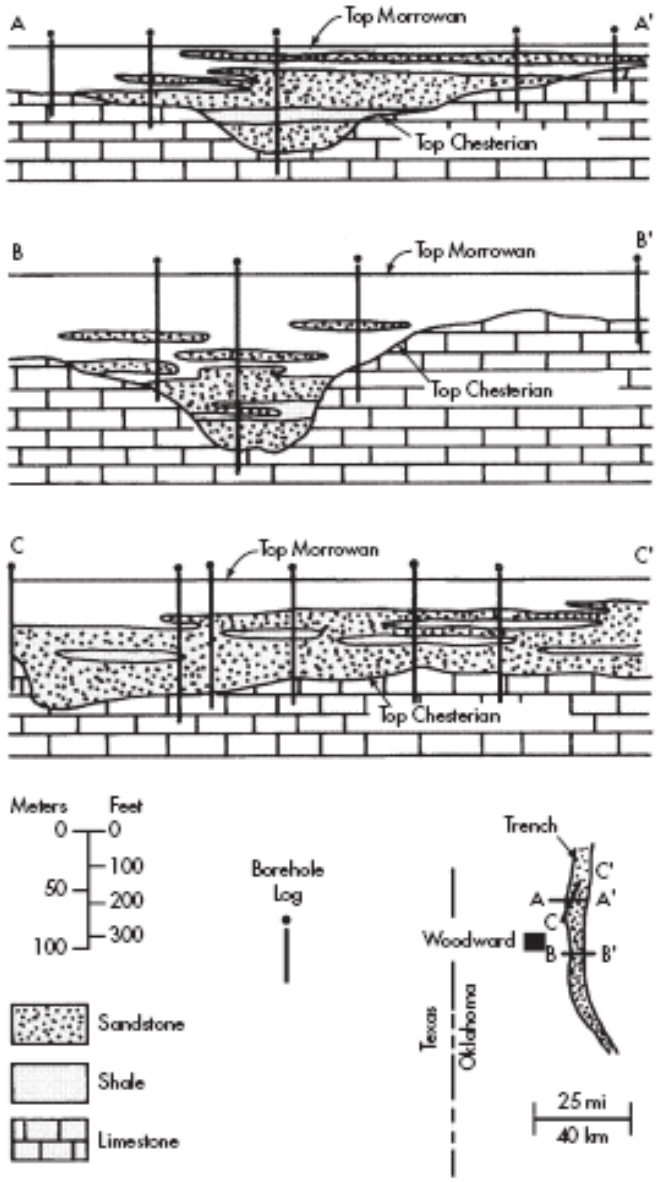
Fig. 2. Areas of known iodine concentrations in the United States. Exceptionally high iodine concentrations in northwest Oklahoma are in Mississippian (Miss.) and Pennsylvanian (Penn.) strata.





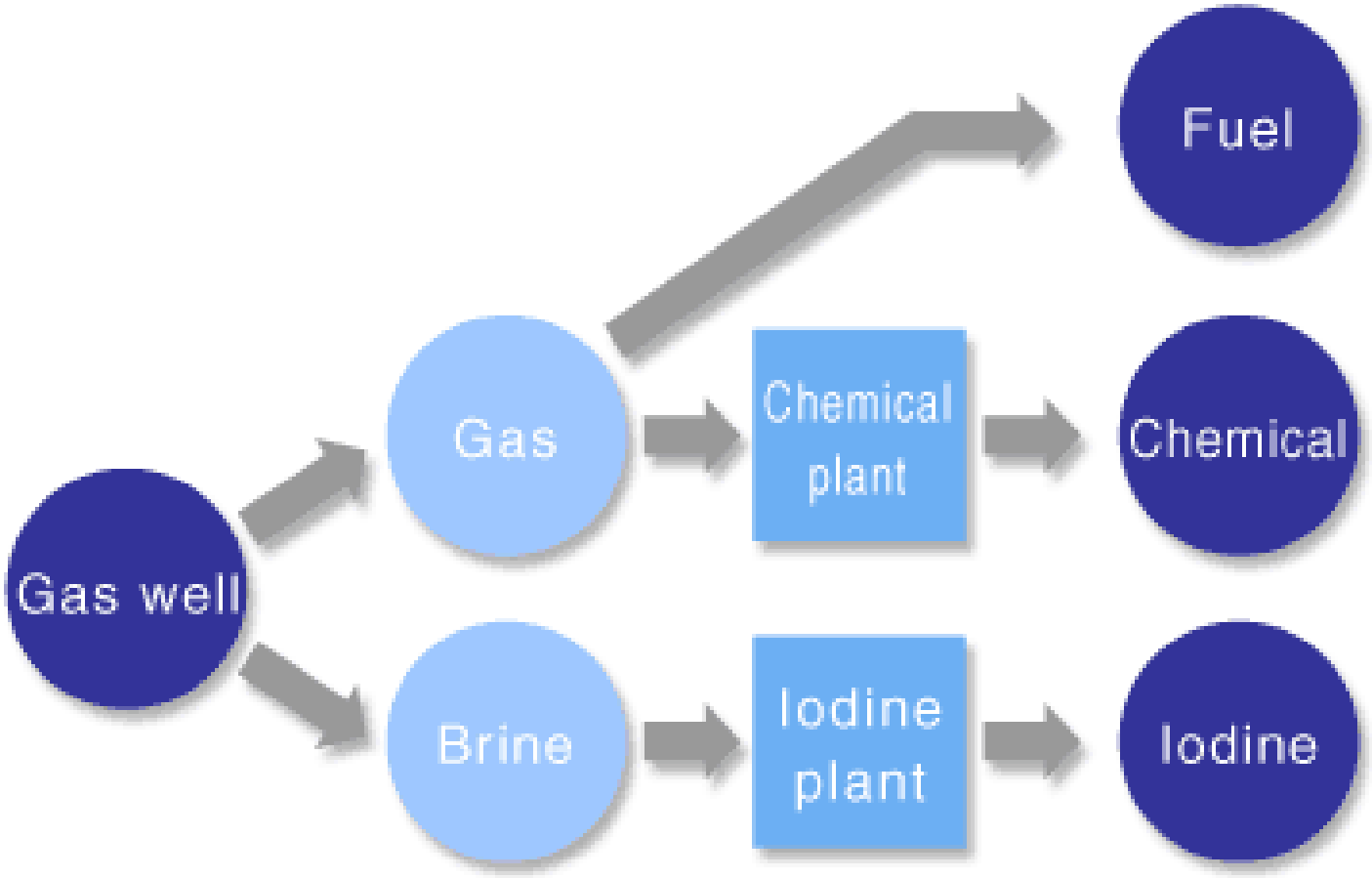
Adapted from Johnson 1989.

Figure 1. Generalized north–south structural cross-section through the Anadarko Basin of western Oklahoma. Iodine-rich brines are produced from basal Pennsylvanian sandstones on the north flank of the basin.

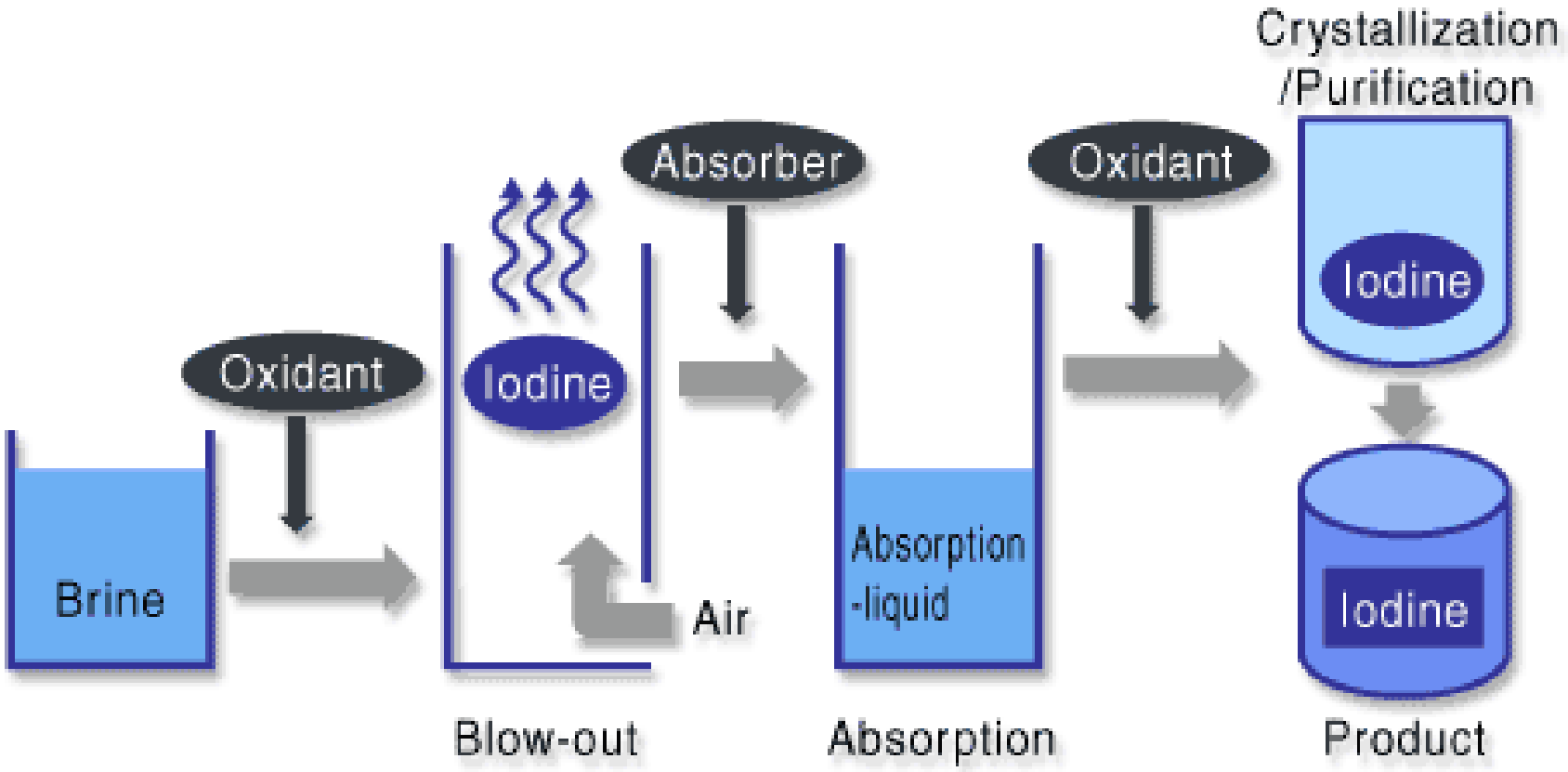


Adapted from Cotton 1978; Johnson 1989.

Figure 2. Cross-sections showing iodine-bearing Morrowan channel sandstones preserved in the Woodward trench, which has been cut into Chesterian limestones. Datum is top of Morrowan strata (length of A–A' and B–B' is about 10 km each; length of C–C' is about 15 km).



http://www.npckk.co.jp/english/technology/iodine/prod.html



http://www.npckk.co.jp/english/technology/iodine/prod.html

Iodine

Salient Statistics—United States:	2013	2014	2015	2016	2017[e]
Production	W	W	W	W	W
Imports for consumption	5,960	5,360	5,630	4,320	4,300
Exports	1,130	1,240	1,210	1,050	1,100
Consumption:					
Apparent[1]	W	W	W	W	W
Reported	4,050	3,740	3,620	4,530	4,500
Price, average c.i.f. value, dollars per kilogram, crude	42.77	37.04	27.74	22.71	20.00
Employment, number[e]	60	60	60	60	60
Net import reliance[2] as a percentage of reported consumption	>50	>50	>50	>50	>50

Recycling: Small amounts of iodine were recycled.

Metric tons
USGS Mineral Yearbooks

Iodine

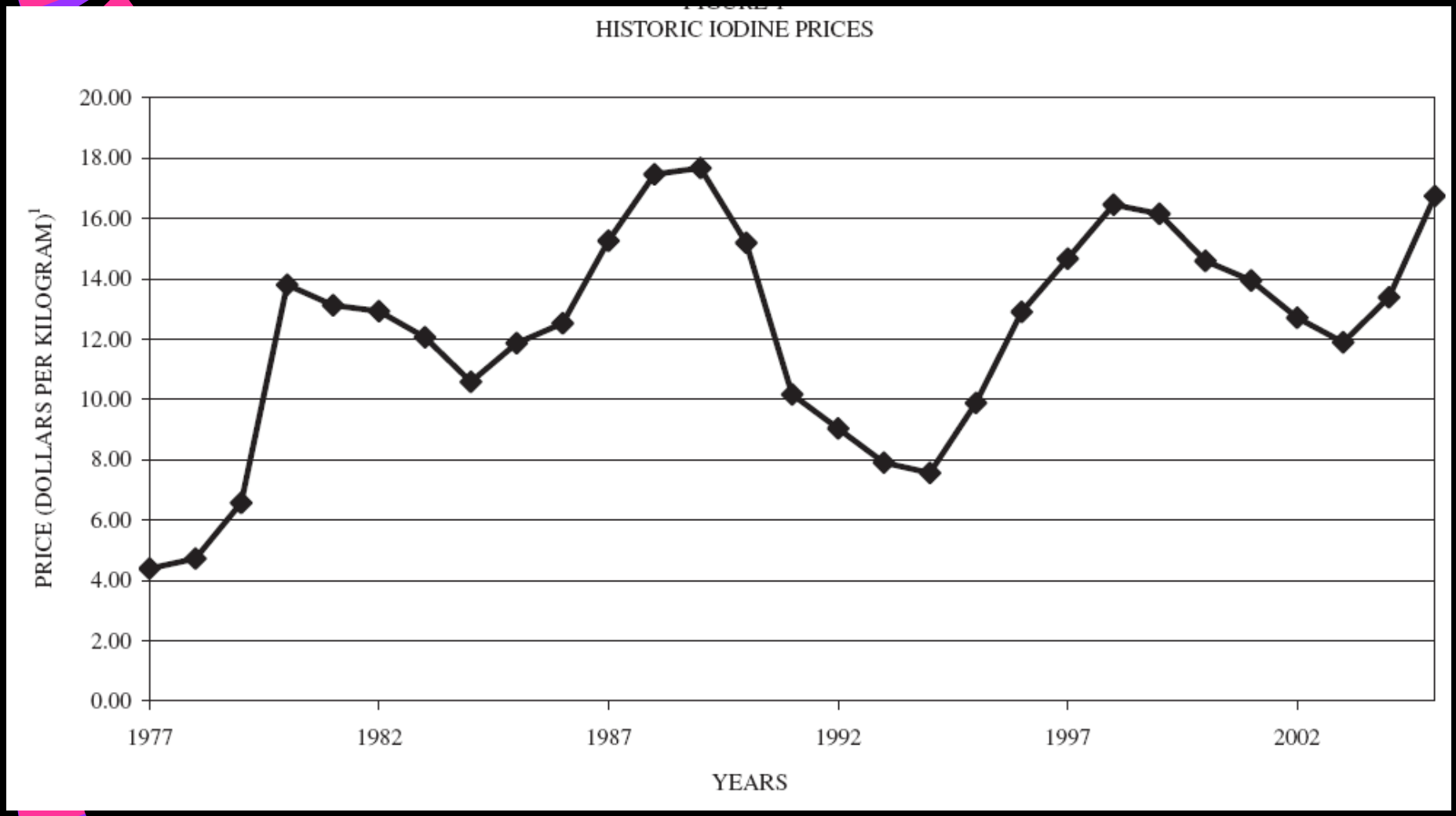
World Mine Production and Reserves: Reserves for Chile were revised based on company and Government reports.

	Mine production		Reserves[3]
	2016	2017[e]	
United States	W	W	250,000
Azerbaijan	210	200	170,000
Chile	21,200	20,000	700,000
Indonesia	15	15	100,000
Japan	10,600	10,600	5,000,000
Russia	—	—	120,000
Turkmenistan	500	500	70,000
World total (rounded)	[4]32,500	[4]31,000	6,400,000

World Resources: In addition to the reserves shown above, seawater contains 0.06 parts per million iodine, and the oceans are estimated to contain approximately 90 billion tons of iodine. Seaweeds of the Laminaria family are able to extract and accumulate up to 0.45% iodine on a dry basis. Although not as economical as the production of iodine as a byproduct of gas, nitrates, and oil, the seaweed industry represented a major source of iodine prior to 1959 and remains a large resource.

Metric tons
USGS Mineral Yearbooks

Iodine


HISTORIC IODINE PRICES
PRICE (DOLLARS PER KILOGRAM)[1]
20.00
18.00
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
1977
1982
1987
1992
1997
2002
YEARS

Health effects of iodine

- contact with the skin can cause lesions
- irritating to the eyes

Indium

Indium

- In
- 0.05 ppm crust
- 0.072 ppm oceanic crust
- Silver-white, malleable, ductile metal
- High plastic properties even at freezing
- Coat glass, forming a mirror surface with equally good reflective properties and more corrosion resistance than silver
- Critical mineral

Indium

- Solar panels
- Flat screens (LCDs)
- Solders and alloys
- Semiconductors


Indium is used to make flat panel displays.

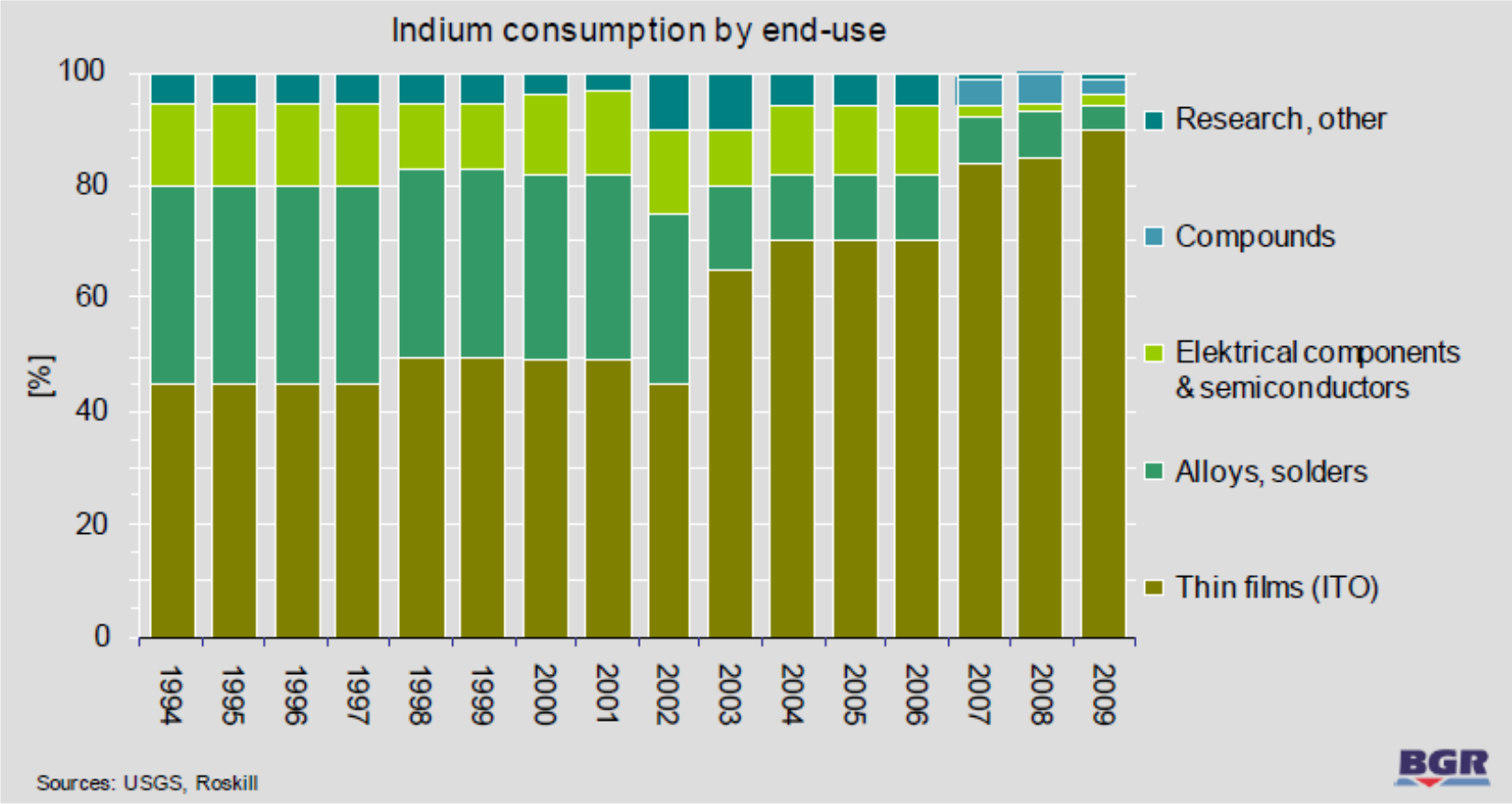

Indium Wire

Indium in solar panels

- 50 metric tons required for enough solar panels to provide 1 gigawatt of energy
- $500/kg in 2009
- 2008—US used 800 megawatts of energy by solar panels connected to the grid (0.1% total US energy)
- 600,000 metric tons reserves in the world in 2009
  - Zinc sulfide deposits
  - Tin-tungsten veins
  - Porphyry copper deposits

Ingots of indium.

Uses



Indium for photovoltaic application particularly in CIS (copper-indium-selenide) thin-film solar cells is a relatively new application with strong growth potential.

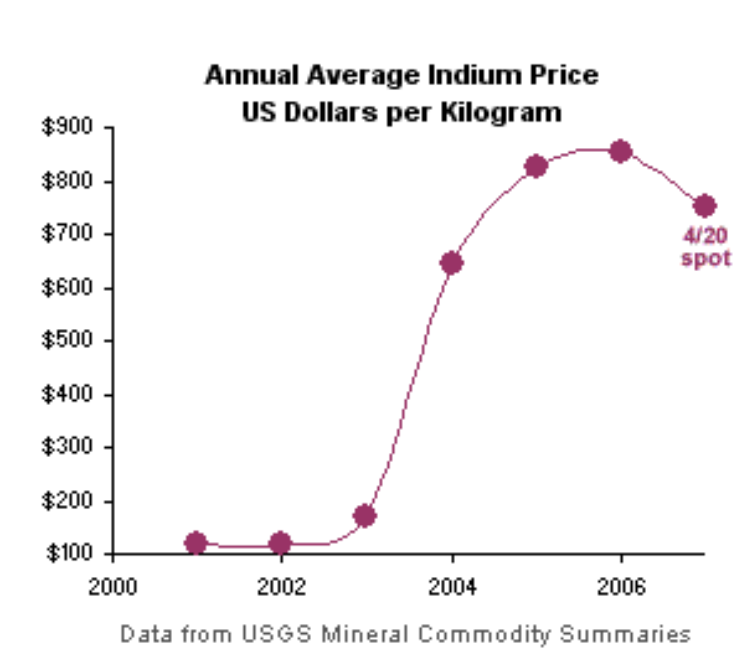
Production

Country	Mine production zinc	Mine production ore concentrate	Estimated indium content in concentrate		Share
	million t Zn content	million t Sphalerit	[ppm]	[t]	[%]
China	2.8	4.2	50	210	45.0
Peru	1.5	2.2	20	44	9.4
Canada	0.7	1.1	37	40	8.6
Australia	1.3	1.9	15	29	6.2
USA	0.7	1.0	20	21	4.5
Mexico	0.5	0.8	20	16	3.4
other	3.6	5.4	20	107	23.0
total	**11.1**	**16.6**	**29**	**467**	

Estimated indium mine production from zinc deposits in 2009 (Roskill 2010).

Production

Salient Statistics—United States:	2013	2014	2015	2016	2017e
Production, refinery	—	—	—	—	—
Imports for consumption	97	123	140	160	120
Exports	NA	NA	NA	NA	NA
Consumption, estimated[1]	97	123	140	160	120
Price, annual average, dollars per kilogram:					
New York dealer[2]	570	705	520	345	360
Free market[3]	NA	NA	410	240	205
Net import reliance[4] as a percentage of estimated consumption	100	100	100	100	100



USGS Mineral Yearbooks
Metric tons

Production

World Refinery Production and Reserves:

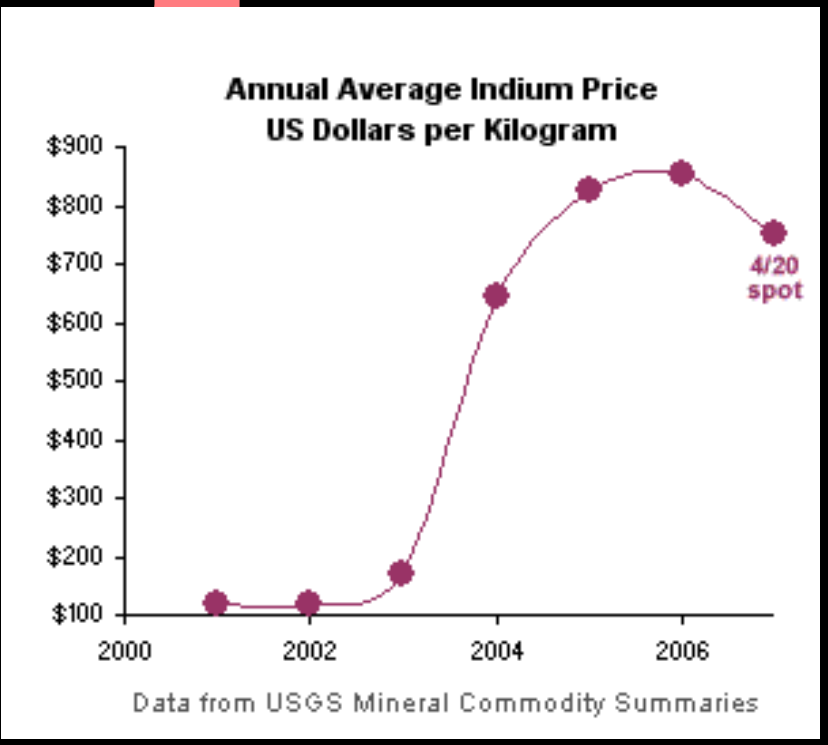
	Refinery production[e]		Reserves[5]
	2016	2017	
United States	—	—	Quantitative estimates of reserves are not available.
Belgium	20	20	
Canada	71	70	
China	300	310	
France	—	20	
Japan	70	70	
Korea, Republic of	210	215	
Peru	10	10	
Russia	5	5	
World total (rounded)	680	720	

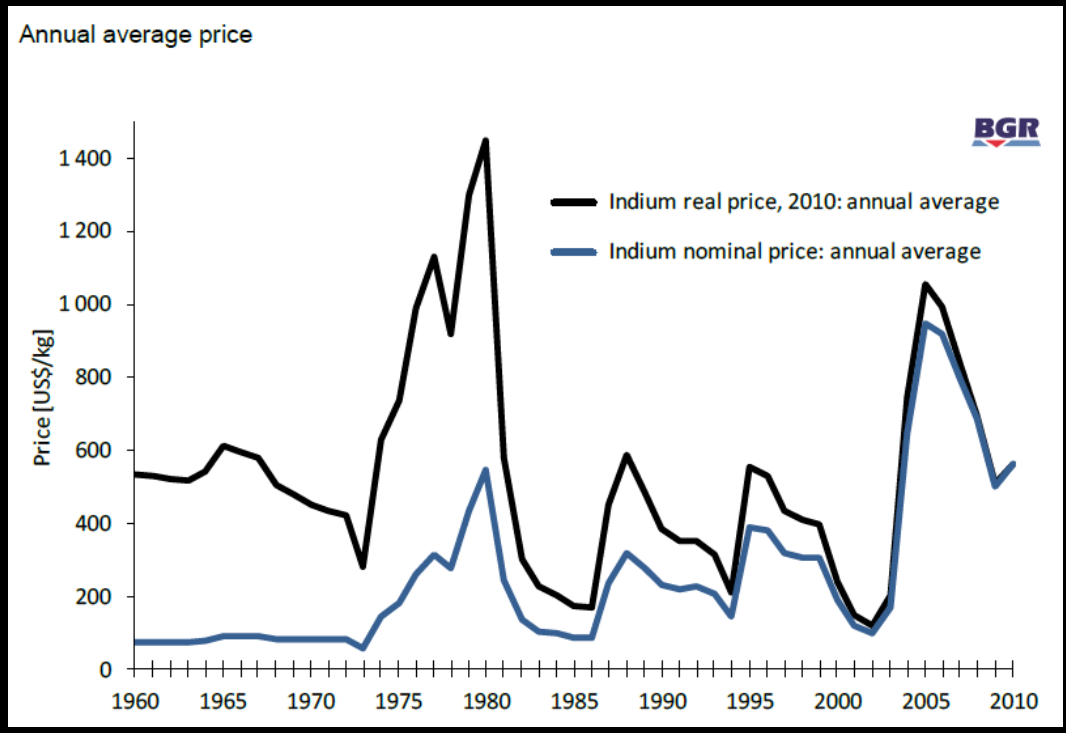
World Resources: Indium is most commonly recovered from the zinc-sulfide ore mineral sphalerite. The indium content of zinc deposits from which it is recovered ranges from less than 1 part per million to 100 parts per million. Although the geochemical properties of indium are such that it occurs in trace amounts in other base-metal sulfides—particularly chalcopyrite and stannite—most deposits of these minerals are subeconomic for indium.

Companies

Companies	Plant location	Refinery capacity [t]	Secondary capacity [t]
Nanjaing Germanium Factory	China	150	
Huludao Zinc	China	50	
Zhuzhou Smelter Group	China	?	
Dowa Metals & Mining Co.	Japan	70	150
Asahi Pretec Corp.	Japan		200
Mitsubishi Mat. Group	Japan		96
Korea Zinc	South Korea	100	100
Umicore SA	Belgium	30	
Teck Resources Ltd	Canada	~75	
Xstrata Plc.	Canada	?	
Doe Run	Peru	45	

Price


Annual Average Indium Price
US Dollars per Kilogram
$900
$800
$700
$600
$500
$400
$300
$200
$100
2000
2002
2004
2006
4/20
spot
Data from USGS Mineral Commodity Summaries


Annual average price
BGR
Indium real price, 2010: annual average
Indium nominal price: annual average
Price [US$/kg]
1 400
1 200
1 000
800
600
400
200
0
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010

Geology

- Base metal deposits
  - Chalcopyrite
  - Sphalerite
  - Stannite
- Tin and tungsten vein deposits
  - Difficult to recover
- Volcanic massive sulfide deposits
- Porphyry deposits
- Skarn deposits
- Bauxite deposits
- Zinc deposits
- Black shale deposits
- Coal
- Mississippi-valley type deposits
- Pegmatites
- Sandstone-hosted base-metal deposits

Mineralogy

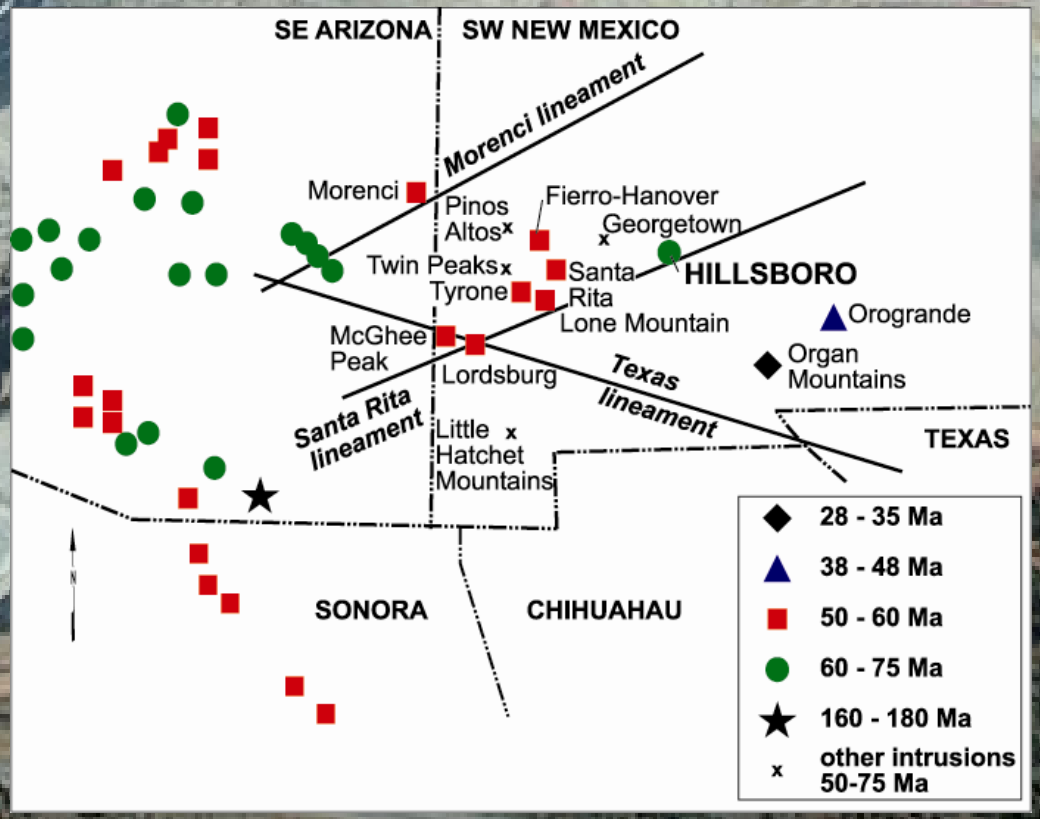
- indit (FeIn2S4)
- roquesit (CuInS2)

Sphalerite	<5—	12,500
Chalcopyrite	<5—	9,800
Stannite	400—	2100
Digenite		1100
Cassiterite	200—	700
Galena		500
Pyrite		100

http://pubs.usgs.gov/of/2005/1209/2005-1209.pdf

Porphyry copper deposits

- Current
  - Gold
  - Silver
  - Molybdenum
- Possible
  - Tellurium
  - Gallium
  - Germanium
  - Indium
  - Others



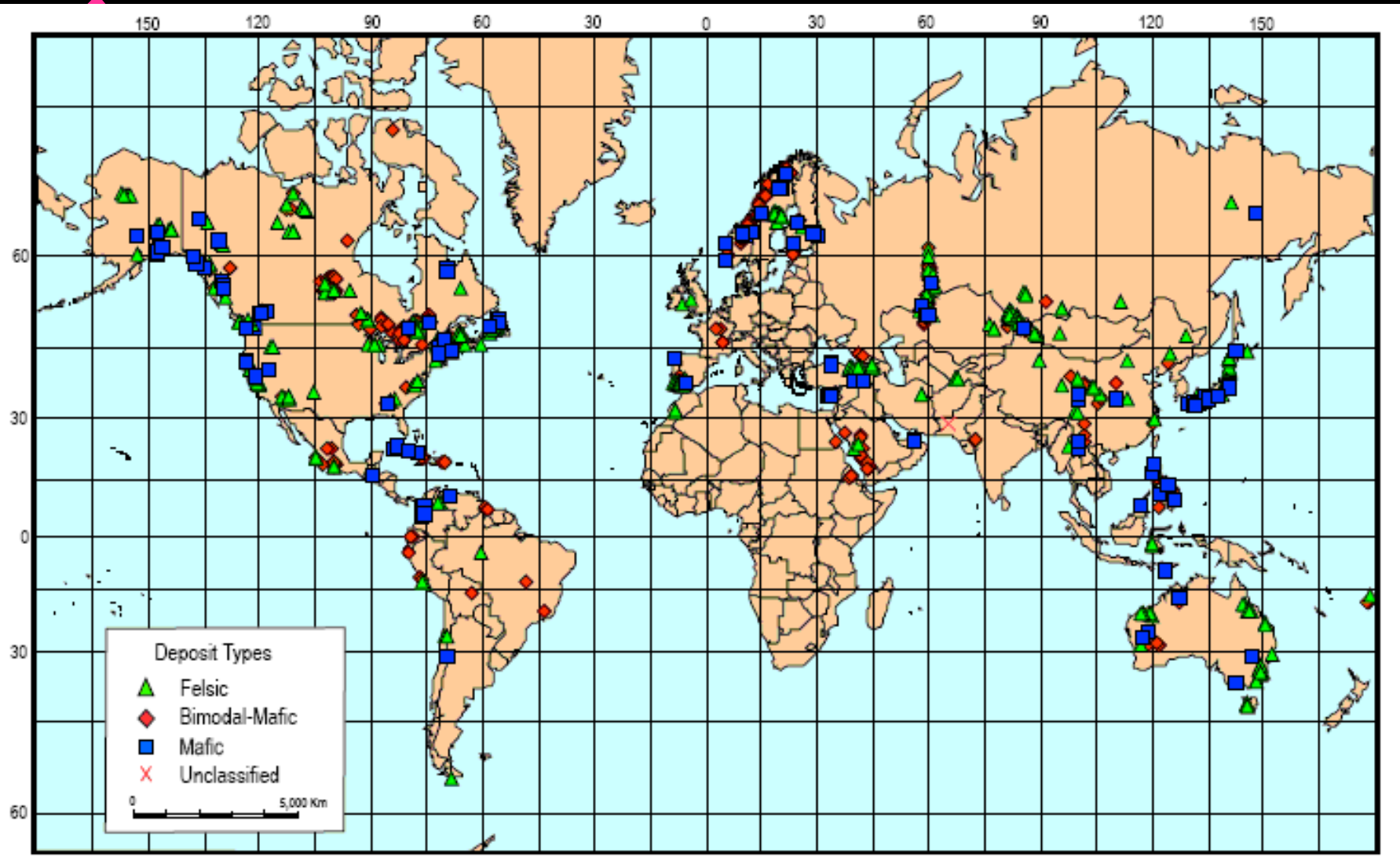


Figure 24. World map showing the distribution of volcanogenic massive sulfide deposit subtypes.

http://pubs.usgs.gov/of/2009/1034/of2009-1034_text.pdf

Geology

Geographic Areas Where the Highest Indium Value Equals or Exceeds 1000 ppm

Mount Pleasant, New Brunswick; Canada
Bingham district, Utah; U.S.A.
Central district, New Mexico; U.S.A.
Central City district; Colorado; U.S.A.

Geographic Areas Where the Highest Indium Values are Between 100-1000 ppm

Cornwall; England
Balmat-Edwards district, New York; U.S.A.
Maine, New Hampshire, Connecticut, and Rhode Island; U.S.A.
Rammelsberg mine, Germany
Argentina, various areas
Yugoslavia, various areas
Metaline district, Washington; U.S.A.
Coeur d'Alene district, Idaho; U.S.A.
Pinos Alto district [incl. Cleveland mine], New Mexico; U.S.A.

http://pubs.usgs.gov/of/2005/1209/2005-1209.pdf

Iron ore

Iron ore—introduction

- Hematite, which is a red iron oxides
- Limonites, which vary from yellow to brown
- Magnetite, which is black
- Largest production Michigan and Minnesota

Magnetite

http://209.51.193.54/scripts/item.exe?ENLARGE+Minerals+Oxides+Magnetite+MAG-24

Hematite, Brazil

Magnetite

Hematite

Goethite

Limonite

Mii Photos

Iron Pyrite Photos

Iron ore—uses

- Steel and iron
- Steel and iron slag
- Iron
- Pigment (ocher, umber, sienna, and metallic paints, brick coloring)
- Coatings
- Heavy cement
- Flux

Iron oxide pigments

- 54% in concrete and other construction materials
- 20% in coatings and paints
- 9% in foundry sands and other foundry uses
- 4% in industrial chemicals
- 3% in animal food
- 2% in glass and ceramics
- 1% in fertilizer
- 1% in plastics, rubber, and cosmetics combined
- 6% in other uses

- Powdered iron: metallurgy products, magnets, high-frequency cores, auto parts, catalyst.
- Radioactive iron (iron 59): medicine
- Iron blue: paints, printing inks, plastics, cosmetics (eye shadow), artist colors, laundry blue, paper dyeing, fertilizer ingredient, baked enamel finishes for autos and appliances, industrial finishes
- Black iron oxide: as pigment, in polishing compounds, metallurgy, medicine, magnetic inks, in ferrites for electronics industry

Iron ore—substitutions

- Ferrous scrap
- Organic dyes
- Synthetic iron oxide pigments

Iron ore—production

Salient Statistics—United States:[2]	2013	2014	2015	2016	2017[e]
Production:					
Iron ore	52.8	56.1	46.1	41.8	46.3
Iron metallics	0.5	2.0	1.4	1.5	2.1
Shipments	53.4	55.0	43.5	43.6	44.7
Imports for consumption	3.2	5.1	4.6	3.0	3.5
Exports	11.0	12.1	7.5	8.8	12.0
Consumption:					
Reported (ore and total agglomerate)	44.2	44.4	38.5	34.5	29.0
Apparent[3]	47.1	47.0	39.7	39.4	36.1
Value, U.S. dollars per metric ton	87.42	84.43	81.19	73.11	75.00
Stocks, mine, dock, and consuming plant, yearend, excluding byproduct ore	2.35	4.46	7.86	6.10	7.70
Employment, mine, concentrating and pelletizing plant, number	5,644	6,273	4,802	4,710	4,500
Net import reliance[4] as a percentage of apparent consumption (iron content of ore)	E	E	E	E	E

Recycling: None. See Iron and Steel Scrap.

USGS Mineral Yearbooks
Million metric tons

Iron ore—production

	Mine production				Reserves[5]	
	Usable ore		Iron content			
	2016	2017[e]	2016	2017[e]	Crude ore	Iron content
United States	42	46	26	28	2,900	760
Australia	858	880	531	545	[6]50,000	[6]24,000
Brazil	430	440	275	280	23,000	12,000
Canada	47	47	29	29	6,000	2,300
China	348	340	216	210	21,000	7,200
India	185	190	114	120	8,100	5,200
Iran	35	35	23	23	2,700	1,500
Kazakhstan	34	34	10	10	2,500	900
Russia	101	100	60	60	25,000	14,000
South Africa	66	68	42	42	1,200	770
Sweden	27	27	16	16	3,500	2,200
Ukraine	63	63	39	39	[7]6,500	[7]2,300
Other countries	116	110	72	68	18,000	9,500
World total (rounded)	2,350	2,400	1,450	1,500	170,000	83,000

World Resources: U.S. resources are estimated to be 110 billion tons of iron ore containing about 27 billion tons of iron. U.S. resources are mainly low-grade taconite-type ores from the Lake Superior district that require beneficiation and agglomeration prior to commercial use. World resources are estimated to be greater than 800 billion tons of crude ore containing more than 230 billion tons of iron.

Iron oxide pigments—production

Salient Statistics—United States:	2013	2014	2015	2016	2017e
Mine production, crude	W	W	W	W	W
Sold or used, finished natural and synthetic IOP	47,200	45,300	53,500	52,500	55,000
Imports for consumption	165,000	175,000	176,000	179,000	190,000
Exports, pigment grade	8,170	8,790	8,930	15,800	13,000
Consumption, apparent[1]	204,000	212,000	221,000	216,000	232,000
Price, average value, dollars per kilogram[2]	1.60	1.58	1.46	1.57	1.54
Employment, mine and mill	50	50	55	60	60
Net import reliance[3] as a percentage of reported consumption	>50	>50	>50	>50	>50

Recycling: None.

USGS Mineral Commodity Yearbooks
Metric tons

Iron oxide pigments—production

World Mine Production and Reserves:

	Mine production		Reserves[4]
	2016	2017[e]	
United States	W	W	Moderate
Austria (micaceous IOP)	3,500	3,500	NA
Cyprus (umber)	3,500	3,500	Moderate
France	1,000	1,000	NA
Germany[5]	200,000	200,000	Moderate
India (ocher)	2,200,000	2,000,000	55,000,000
Pakistan (ocher)	40,000	40,000	Moderate
Spain (ocher and red iron oxide)	16,000	16,000	Large
World total	[6]NA	[6]NA	Large

World Resources: Domestic and world resources for production of IOPs are adequate. Adequate resources are available worldwide for the manufacture of synthetic IOPs.

Iron ore—production

TABLE 6
CONSUMPTION OF IRON ORE AT U.S. IRON AND STEEL PLANTS, BY TYPE OF PRODUCT[1]

(Thousand metric tons)

Type of product	2002	2003
Blast furnaces:		
Direct-shipping ore	234	193
Pellets	48,400	50,400
Sinter[2]	8,880	8,850
Total	57,500	59,500
Steelmaking furnaces:		
Direct-shipping ore	61	492
Pellets	417 r	345
Sinter[2]	138 r	134
Total	616 r	971
Grand total	58,100 r	60,400

rRevised.

[1]Data are rounded to no more than three significant digits; may not add to totals shown.

[2]Includes briquettes, nodules, and other.

Source: American Iron and Steel Institute.

TABLE 6

NATURAL IRON OXIDE PIGMENTS: ESTIMATED WORLD PRODUCTION, BY COUNTRY[1, 2]

(Metric tons)

Country[3]	2006	2007	2008	2009	2010
Austria	5,000	5,000 r	5,000	4,000 r	4,000
Brazil	2,000	2,000	2,000	2,000	2,000
Cyprus, umber	12,000	12,000	12,000	12,000	12,000
France	2,791 [4]	2,800	2,800	2,800	2,800
Germany[5]	242,264	240,310	251,412	209,172	233,909 [4]
India, ocher	370,000	375,000	380,000	385,000	390,000
Iran	2,600	2,600	2,600	2,600	2,600
Italy	500	500	500	500	500
Lithuania	4	4	4	4	4
Pakistan, ocher	5,500	6,000	6,000	6,200 r	6,000
Paraguay, ocher	250	250	250	250	250
South Africa	590 [4]	232 [4]	39 [4]	183 r, 4	244
Spain, ocher	140,000	140,000	140,000	140,000	140,000
Turkey[6]	206,000	260,000	220,000	100,000	100,000
United Kingdom, iron oxides and hydroxides[7]	8,913 [4]	8,000	8,000	8,000	8,000
United States	W	W	W	W	W

TABLE 12

AVERAGE UNIT VALUE FOR SELECTED IMPORTS OF IRON ORE IN 2003[1]

Type of product	Country of origin	Average unit value[2] (dollars per metric ton, gross weight)
Concentrates	Canada	17.57
Fine ores	Australia	8.61
Do.	Brazil	16.48
Pellets	do.	28.90
Do.	Canada	29.58

[1]Includes agglomerates.

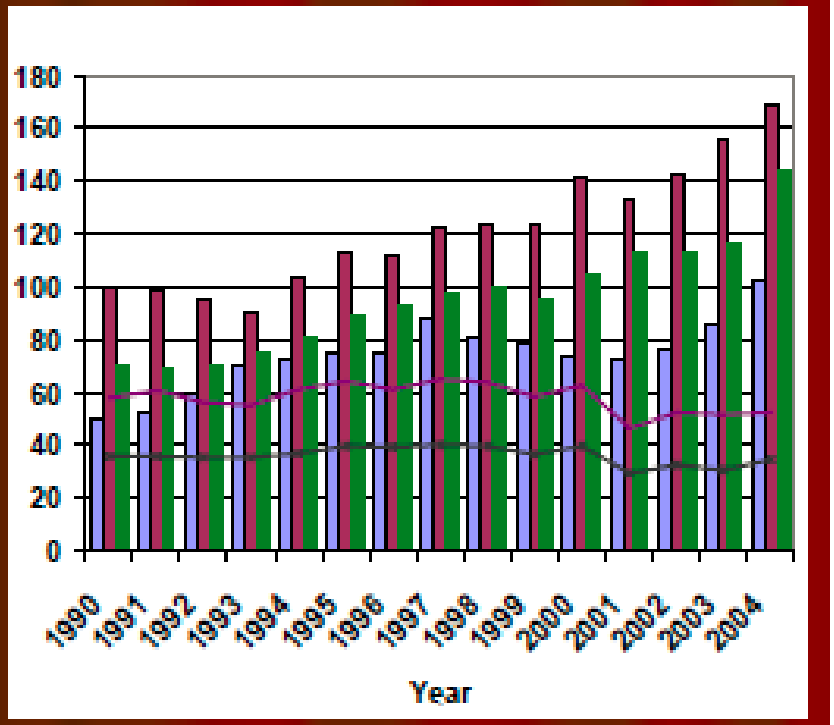
[2]Weighted averages of individual customs values.

Source: U.S. Census Bureau.

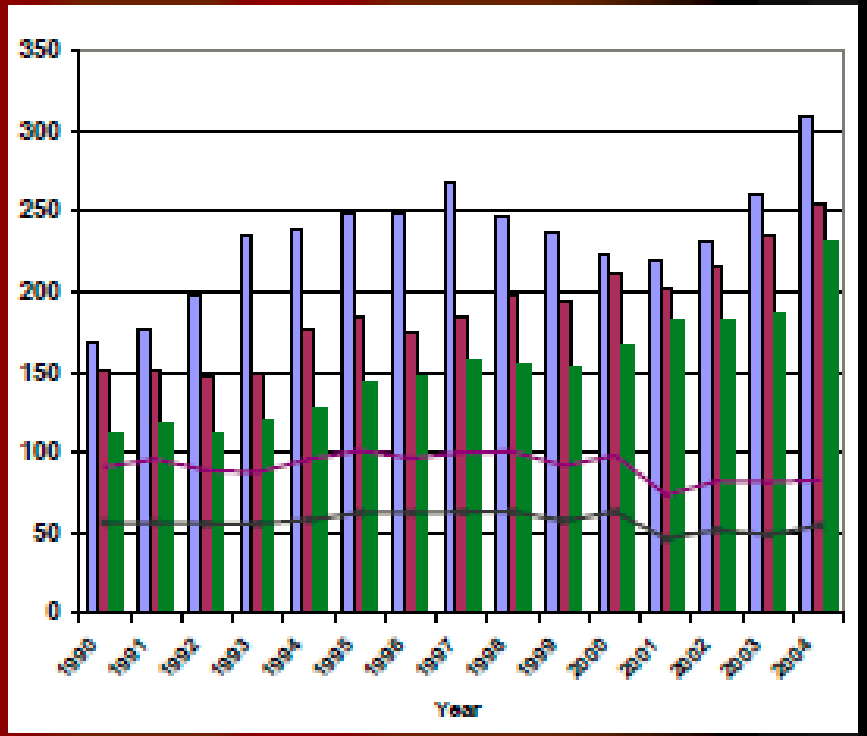
Major Producers of Iron Ore

(million metric tons)

Fe content



Gross Weight



China Brazil Australia U.S. U.S. + Canada

Source: U.S. Geological Survey Minerals Yearbook

Iron Ore Reserves and Expected Year of Depletion

Canada	Reserves (Mt)	Year
• Iron Ore Company of Canada	1,400	2040
• Quebec Cartier	836	2040
• Wabush	58	2014
United States		
• Keetac and Minntac (U.S. Steel)	680	2047
• Northshore		2070
• Hibbing Taconite	180	2025
• United Taconite	110[e]	2029
• Empire	29	2008
• Tilden	290	2040

e estimate

Source: Skillings Mining Review; Company Annual Reports

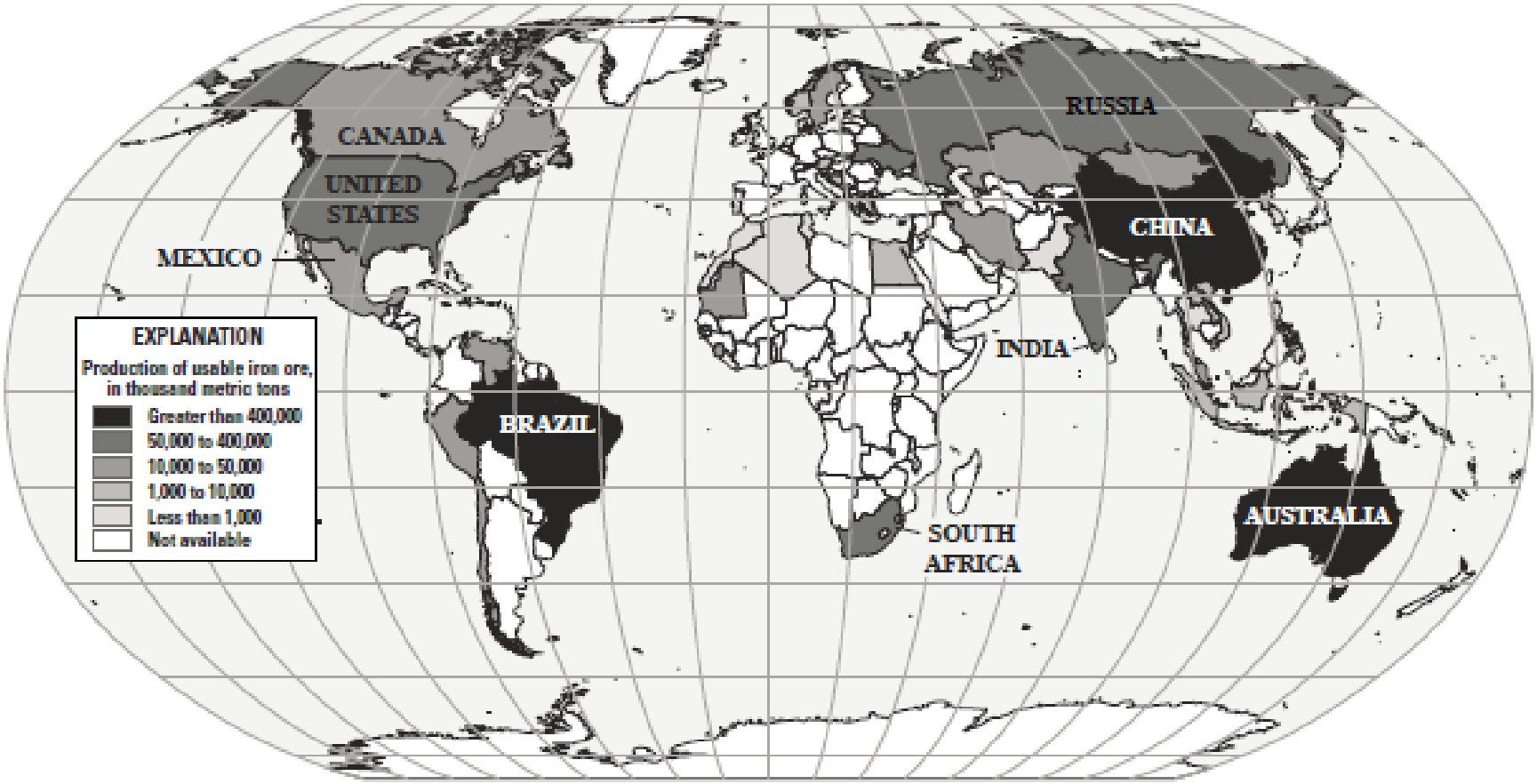
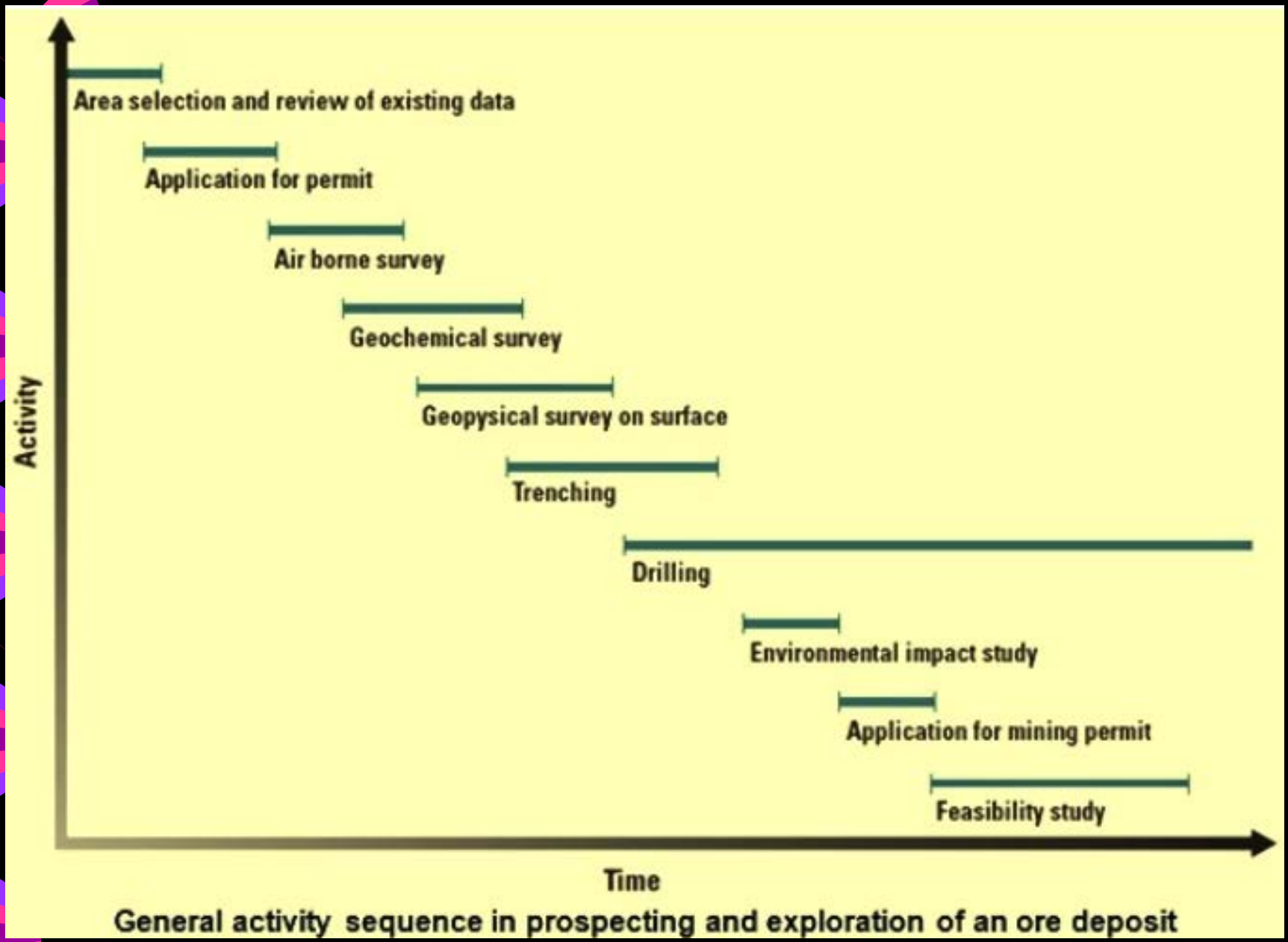


Figure 1. Global production of usable iron ore in 2014. Source: U.S. Geological Survey.

USGS Mineral Yearbooks

Geology

- Banded iron formations (Precambrian sedimentary) (taconite)
  - switched from being a reducing environment to an oxidizing environment (blue-green algae)
- Magmatic (granite in Malaysia, Indonesia)
- Skarns
- Hydrothermal
- Metamorphic accumulations (Savage River, Tasmania)
- Volcanic flows in Atacama Desert, Chile
- Placers (beach sands)



General activity sequence in prospecting and exploration of an ore deposit

Iron ore—geology

TABLE 2

EMPLOYMENT AND PRODUCTION STATISTICS FOR IRON OPERATIONS IN THE UNITED STATES IN 2014, BY STATE[1]

(Thousand metric tons, net weight, unless otherwise specified)

District and State	Number of operations	Number of employees[2]	Worker hours (thousands)	Usable ores					Shipments	Average iron content[4] (percent)
				Crude ore	Pellets	Iron metallics	Other[3]	Total		
Indiana	2	60	115	--	(5)	250 [6]	--	250	250	62.2
Louisiana	1	25	12	--	--	1,460 [6]	--	1,460	1,450 [6]	--
Michigan	2	1,285	2,730	35,700 [6]	12,100 [6]	--	--	12,100	11,900 [6]	60.8
Minnesota	11	4,514	9,050	145,000	41,400	241 [6]	1,560	43,200	42,100	63.4
Utah	1	389	166	3,330 [6]	--	--	998 [6]	998	998 [6]	65.1
Total or average	16	6,273	12,100	184,000	53,500	1,950	2,560	58,000	56,700	63.2

-- Zero.

[1]Data are rounded to no more than three significant digits, except number of employees; may not add to totals shown.

[2]Does not include professional or clerical workers at mines, pelletizing plants, and maintenance shops or research lab workers.

[3]Includes other, unspecified products not included in other categories; may include concentrates, direct-shipping ore, flux, and pellet chips.

[4]Data for iron metallics (cold pig iron, direct-reduced iron, hot-briquetted iron, iron nuggets, and sponge iron) not included.

[5]Iron pellets were produced by Magnetation Inc. but not included in production totals as they were not mine production.

[6]Calulcated, estimated, or reported from publicly available data.

Iron ore—production

TABLE 9
IRON ORE: WORLD PRODUCTION, BY COUNTRY[1, 2]

(Thousand metric tons)

	Usable ore, unless otherwise specified					Iron content				
Country	2010	2011	2012	2013	2014[e]	2010	2011	2012	2013	2014[e]
Algeria	1,469	1,320	1,784	1,067	911	771	693	937 r	560 r	478
Australia	433,000	488,000	555,500 r	682,700 r	774,200 3	271,000	277,000	336,000 r	413,000 r	468,000
Austria	2,070 r	2,210 r	2,140 r	2,320 r	2,300	1,293 r	1,379 r	1,339 r	1,452 r	1,438 3
Azerbaijan	58	214	207 r	141 r	91	36 r	134 r	129 r	88 r	57
Bosnia and Herzegovina	1,401	1,891	2,076	2,122 r	2,128 3	876 r	1,180 r	1,300 r	1,330 r	1,330
Brazil	372,120	398,131	400,822	386,270	411,183 3	248,000 r	265,000 r	258,000 r	246,000 r	262,000
Canada	36,178 r	35,705 r	38,892 r	42,063 r	44,196 3	23,300	21,000	25,000 r	26,000	27,300
Chile	9,130 r	12,624 r	17,330	17,109	18,866 3	5,850 r	7,750 r	9,430 r	9,090 r	10,100
China, crude ore[4]	1,080,000 r	1,340,000 r	1,330,000	1,450,000	1,510,000	XX	XX	XX	XX	XX
China, usable ore[4]	371,231	442,179	420,206	417,287	410,000	230,000 r	274,000 r	261,000 r	259,000 r	254,000
Colombia	77	174	809 r	710	676 3	48 r	109 r	506 r	444 r	423
Egypt	2,314 r	3,321 r	3,930 r	3,320 r	3,300	1,660 r	1,960 r	2,320 r	1,960 r	1,950
Greece[5]	2,200 r, e	2,250 r	2,306 r	2,221 r	2,380	1,030 r	1,060 r	1,080 r	1,040	1,120
India[6]	207,157 r	168,582 r	136,618 r	152,433 r	129,103 3	128,000 r	104,000 r	84,000 r	94,000 r	80,000
Indonesia	4,600 r	4,475 r	4,800 r	4,000 r	3,013 3	2,830 r	2,750 r	2,950 r	2,460 r	1,850
Iran[6]	35,000	44,335	36,000 r	38,000 r	33,000	16,500	20,900	17,000 r	17,900 r	15,600
Kazakhstan	24,016 r	24,736 r	25,889 r	25,228 r	24,561 3	13,700 r	14,100	14,800 r	14,400 r	14,100
Korea, North	2,097 r	2,508 r	2,412 r	3,054 r	4,500 3	1,220 r	1,460 r	1,400 r	1,770 r	2,610
Korea, Republic of	513	542	593	663 r	660	287 r	303 r	332	371 r	369
Laos	51	43	316	1,459	1,850	32	26	196	561	712
Liberia	--	1,300 r	3,300 r	5,103 r	5,740	--	780 r	1,980 r	3,110 r	3,500
Malaysia	3,558 r	8,078	12,144 r	11,588 r	11,900	2,220 r	5,050 r	7,590 r	7,240 r	7,440
Mauritania	11,534	11,160	11,200	13,400 r	14,000	7,500	7,250	7,280	8,380 r	8,780
Mexico	13,998	12,806	14,915	18,840 r	16,600	8,750 r	8,000 r	9,320 r	11,800 r	10,400
Mongolia	3,203	5,678	7,561	6,736 r	6,390	2,050	3,630 r	4,760	4,120 r	3,890
Morocco	45	79	261	301 r	300	24	43	141 r	163 r	162
New Zealand[7]	2,439	2,357	2,395	3,157 r	2,400	1,400	1,300	1,320	1,740 r	1,320
Norway	3,292	3,427	3,911	3,409 r	3,850	1,930 r	2,050 r	2,410 r	2,320 r	2,620
Pakistan[6]	418	430	412 r	193 r	255	253 r	260 r	249 r	117 r	154
Peru	9,160 r	10,626 r	10,132 r	10,126 r	10,731 3	6,140 r	7,120 r	6,790 r	6,790 r	7,190
Philippines	--	468	1,800 e	1,057	827 3	--	293	1,150	793	517
Russia	95,272 r	103,607 r	104,010 r	102,156 r	102,019 3	57,600 r	62,700 r	62,900 r	61,800 r	61,700
Sierra Leone	--	339 r	5,203 r	11,895 r	12,000	--	195 r	2,990 r	6,840 r	6,900
South Africa	58,709	58,057	67,100	71,645 r	80,759 3	36,900	36,500	42,900	45,700	51,500
Sweden	28,797 r	30,840 r	25,927 r	37,411 r	37,400 3	17,400 r	18,700 r	15,700 r	22,600 r	22,600
Thailand	904 r	489 r	256 r	334 r	532	547 r	296 r	155 r	202 r	322
Tunisia	180 r	172 r	223 r	244 r	240 3	109 r	103 r	135 r	148 r	145
Turkey	5,378 r	6,661 r	8,102 r	8,589 r	7,790	3,250 r	4,030 r	4,900 r	5,200 r	4,710
Ukraine	63,773 r	65,807 r	66,379 r	67,020 r	67,874 3	38,600 r	39,800 r	40,200 r	40,500 r	41,100
United States	49,900	56,200 r	54,700 r	52,800 r	56,100	31,300	34,300	33,400	33,000 r	35,500
Venezuela	14,004	17,037	15,124	16,800 r	18,000 3	8,700 r	10,600 r	9,400	10,400 r	11,200
Vietnam	3,721	4,474	2,870	4,708 r	4,355	1,970 r	2,370 r	1,520 r	2,500 r	2,310
Other[8, 9]	93	139	203	147	147	57	85	120	91	91
Total	1,870,000 r	2,030,000 r	2,070,000 r	2,230,000 r	2,330,000	1,170,000 r	1,240,000 r	1,280,000 r	1,370,000 r	1,430,000

[e]Estimated. [r]Revised. -- Zero. XX Not applicable.

[1]World totals, U.S. data, and estimated data are rounded to no more than three significant digits; may not add to totals shown. Includes data available through December 15, 2015.

[2]Production of usable ore represents total for all iron ore products used in steelmaking, unless otherwise noted, produced in the country, excluding agglomerates produced from imported iron ore. Iron content indicates either reported weight of contained iron ore or metal content as calculated based on surveyed and reported figures or estimates.

[3]Reported figure.

[4]Data for China are for reported usable ore and crude ore, as opposed to only crude ore used in prior reports. China's crude ore production is not included in "Total."

[5]Production includes alternative iron ore source as follows: Greece (nickeliferous iron ore) and New Zealand (titaniferous magnetite beach sands).

[6]Production is based on fiscal year, with starting dates as follows: India, April 1; Iran, March 21; and Pakistan, July 1.

[7]Includes the following countries for which inadequate information is available: Bhutan, Guatemala, Kenya, Nigeria, Portugal (manganiferous iron ore), Togo, and Uganda.

China, Australia and Brazil

Great Lakes - Seaway Shipping

Kyanite

Kyanite—introduction

- Wide variation in hardness 4-7.4
- Specific gravity 3.2-3.6
- Bluish-gray to gray
- Lath-like crystals
- Polymorph with two other minerals; andalusite and sillimanite
- 60% alumina – which means that it is a relative cheap source of refractoriness

Kyanite—introduction

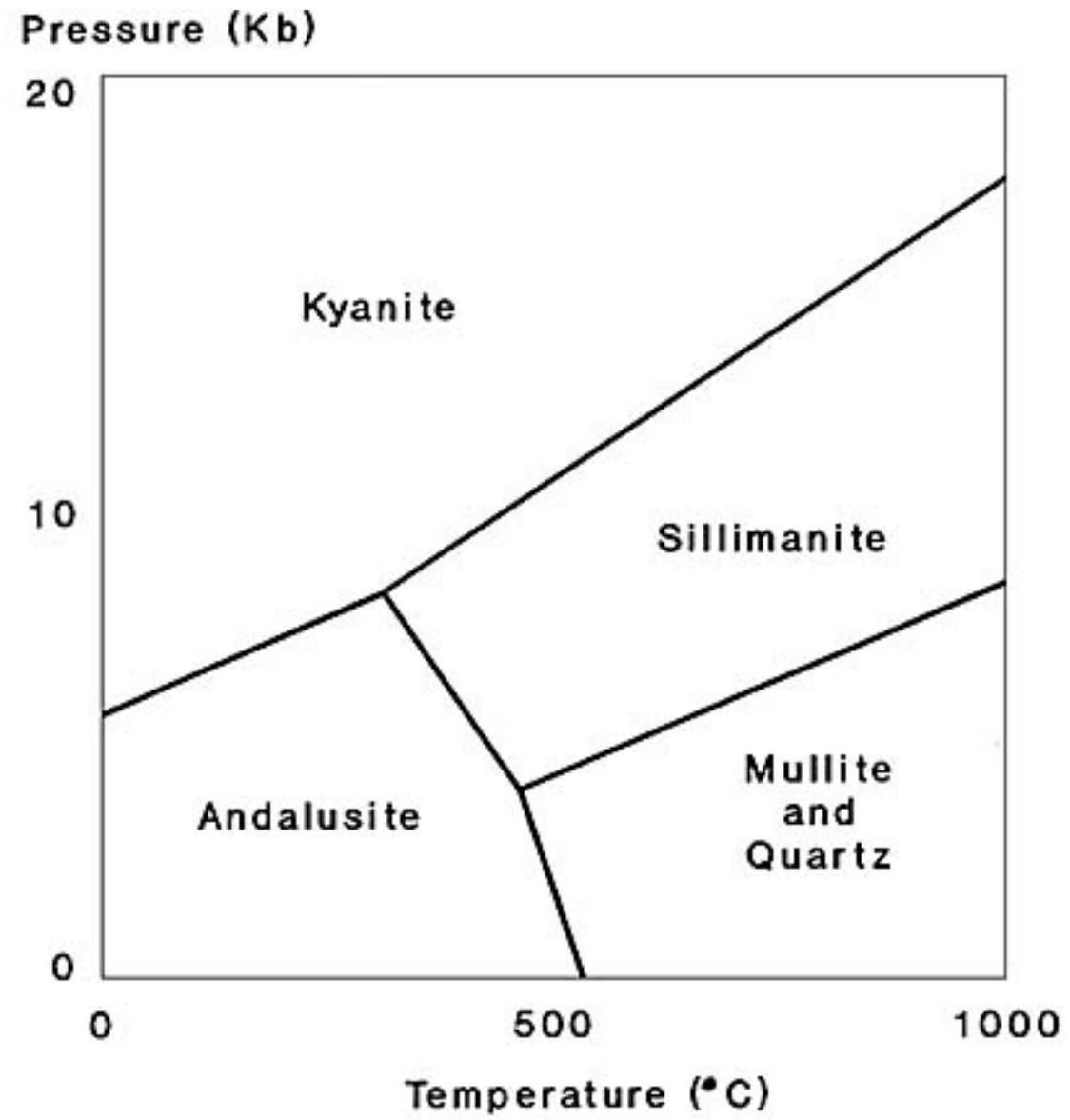
- Al2SiO5
- Polymorph with two other minerals; andalusite and sillimanite
- But differing crystal structures

http://www.kyanite.com/kyaniteandproducts.html

Kyanite—properties

- conversion to mullite ($Al_6Si_2O_{13}$) and SiO_2 at 1400-1500 deg C, expands irreversibly by up to 18%, thereby offsetting the firing shrinkage of other raw materials, especially clay, in ceramic bodies and refractories
- 1 metric ton (t) of aluminosilicate concentrate yields approx 0.88 t of mullite

Fig. 2. Mineral phases within the Al2P3 ¥ SiO2.



Anon., 1985.

Kyanite—properties

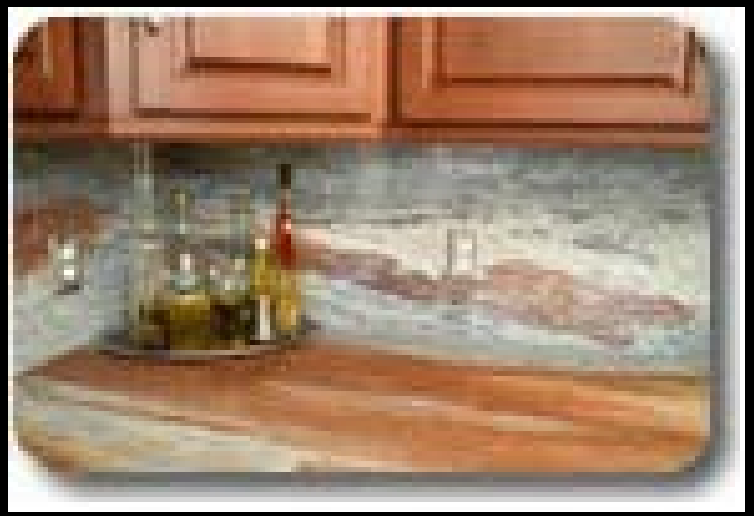
- Increases the fired strength
- Resistance to deformation under load
- Thermal resistivity of refractories

Table 1. Chemical and physical properties of kyanite, andalusite, and sillimanite

	Kyanite	Andalusite	Sillimanite
Chemical formula	Al_2SiO_5	Al_2SiO_5	Al_2SiO_5
Composition	Al_2O_3 63.2% SiO_2 36.8%	Al_2O_3 63.2% SiO_2 36.8%	Al_2O_3 63.2% SiO_2 36.8%
Type	Aluminum silicate	Aluminum silicate	Aluminum silicate
Crystal system	Triclinic	Orthorhombic	Orthorhombic
Cleavage	(100) perfect (010) good	(110) good (100) poor	(010) good
Specific gravity	3.56–3.66	3.16–3.20	3.23
Hardness	5–7	7.5	6–7
Temperature at which mullite is formed	1,100°C–1,480°C	1,450°C–1,500°C	1,550°C–1,650°C
Volume change during calcination	Sizeable increase	Very slight increase	Slight increase
Density after calcining at 1,445°C	3.05	3.04	3.10

Kyanite—uses

- Refractories, 90% (high melting points)
  - iron and steelmaking
  - manufacture of chemicals, glass, nonferrous metals, and other materials
- 10% in other uses
  - Dimension stone



"Ceramic engineers the world over harness the unique and beneficial properties of our minerals to improve the performance of their products."

http://www.kyanite.com/refractory.html

"Ceramic engineers the world over harness the unique and beneficial properties of our minerals to improve the performance of their products."

http://www.kyanite.com/refractory.html

brakes

"Ceramic engineers the world over harness the unique and beneficial properties of our minerals to improve the performance of their products."

http://www.kyanite.com/refractory.html

Kyanite—substitutions

- Andalusite
- Sillimanite
- Two types of synthetic mullite (fused and sintered), superduty fire clays, and high-alumina materials are substitutes for kyanite in refractories.
- Bauxite
- Kaolin and other clays
- Silica sand

Kyanite—production

Salient Statistics—United States:	2013	2014	2015	2016	2017[e]
Production:					
Mine	[1]110	[1]89	[1]109	[1]79.7	90
Synthetic mullite	W	W	W	W	W
Imports for consumption (andalusite)	4	4	12	3	8
Exports (kyanite)	42	40	40	37	40
Consumption, apparent	W	W	W	W	W
Price, average, dollars per metric ton:[2]					
U.S. kyanite, raw concentrate	300	260	270	270	270
U.S. kyanite, calcined	450	370	410	410	420
Andalusite, Transvaal, South Africa	320	340	330	330	340
Employment, kyanite mine, office, and plant, number[e]	140	150	155	150	150
Employment, mullite plant, office, and plant, number[e]	210	230	220	210	210
Net import reliance[3] as a percentage of apparent consumption	E	E	E	E	E

Recycling: Insignificant.

Alabama and Georgia
USGS Mineral Yearbooks
Thousand metric tons

Kyanite—production

World Mine Production and Reserves:

	Mine production 2016	Mine production 2017[e]	Reserves[4]
United States (kyanite)	80	90	Large
India (kyanite and sillimanite)	73	75	1,600
Peru (andalusite)	40	40	NA
South Africa (andalusite)	180	180	NA
World total (rounded)	[5]NA	[5]NA	NA

World Resources: Large resources of kyanite and related minerals are known to exist in the United States. The chief resources are in deposits of micaceous schist and gneiss, mostly in the Appalachian Mountains and in Idaho. Other resources are in aluminous gneiss in southern California. These resources are not economic to mine at present. The characteristics of kyanite resources in the rest of the world are thought to be similar to those in the United States. Significant resources of andalusite are known to exist in China, France, Peru, and South Africa; kyanite resources have been identified in Brazil, India, and Russia; and sillimanite has been identified in India.

USGS Mineral Yearbooks
Thousand metric tons

Kyanite—production

TABLE 3
KYANITE AND RELATED MINERALS: ESTIMATED WORLD PRODUCTION, BY COUNTRY[1, 2]

(Metric tons)

Country and commodity[3]	1999	2000	2001	2002	2003
Australia:					
Kyanite	1,000	1,000	1,000	1,000	1,000
Sillimanite[4]	100	100	100	300	300
Brazil, kyanite	600	600	600	600	600
China, unspecified	3,000	3,100	3,150	3,200	3,200
France, andalusite	70,000	65,000	65,000	65,000	65,000
India:					
Kyanite	5,000	5,000	5,500	6,000	6,000
Sillimanite	12,000	12,000	13,000	14,000	14,000
South Africa, andalusite	136,949 [5]	182,674 [5]	193,225 [5]	165,000 [r, 5]	220,000
Spain, andalusite	2,500	2,500	2,500	2,500	2,500
United States:[6]					
Kyanite	90,000	90,000	90,000	90,000	90,000
Mullite, synthetic	39,000	40,000	40,000	40,000	40,000
Zimbabwe, kyanite	4,000	10,970 [5]	9,682 [5]	5,657 [r, 5]	4,000

[r]Revised.

[1]U.S. and estimated data are rounded to no more than three significant digits.

[2]Owing to incomplete reporting, this table has not been totaled. Table includes data available through March 19, 2004.

[3]In addition to the countries listed, small amounts of kyanite were produced in Kenya in 2000; a number of other nations produce kyanite and related materials, but output is not reported quantitatively, and no reliable basis is available for estimation of output levels.

[4]In addition, about 7,000 metric tons per year of sillimanite clay (also called kaolinized sillimanite) that contains 40% to 48% Al_2O_3 is produced.

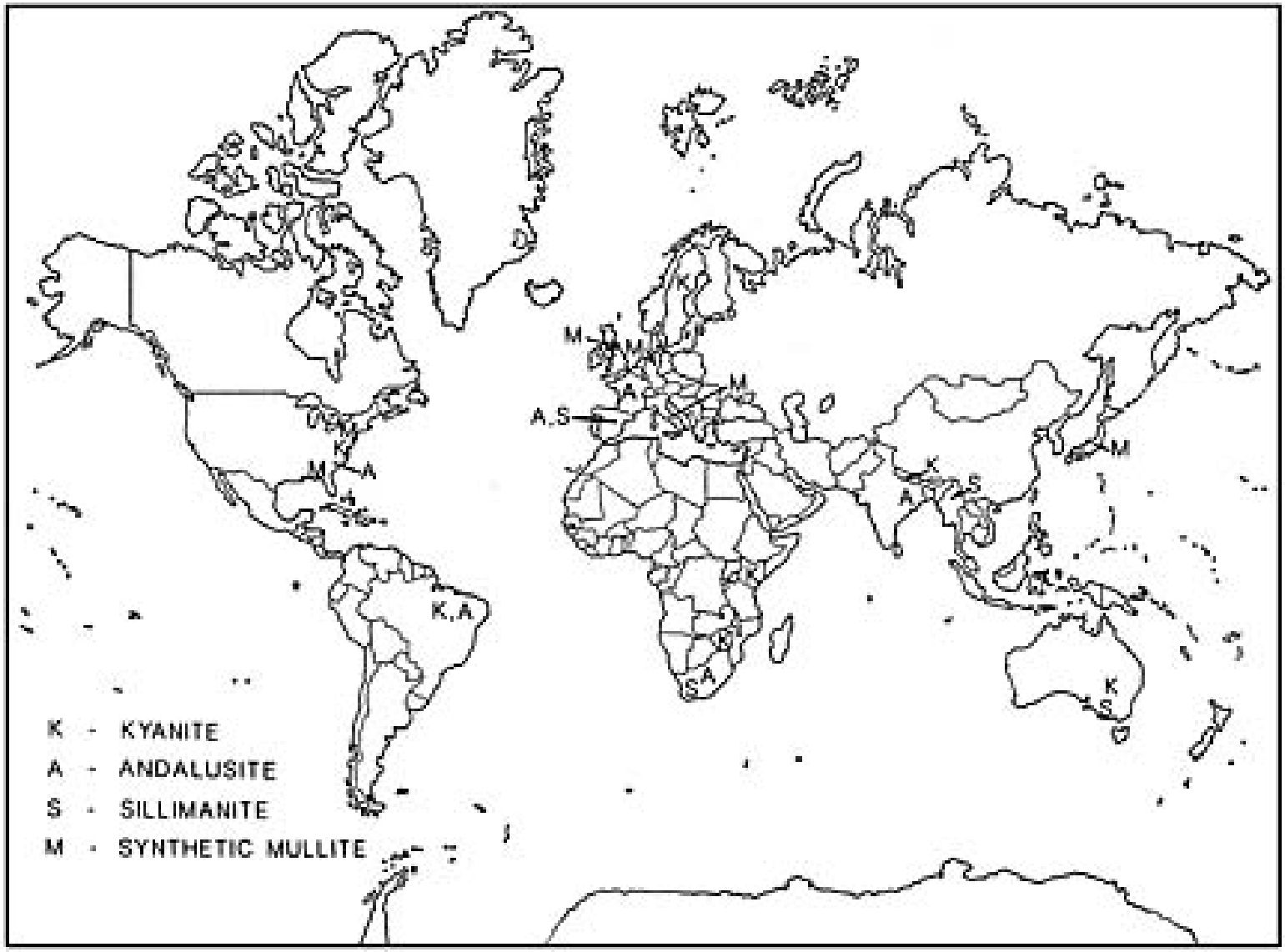
[5]Reported figure.

[6]Source: Dickson, Ted, 2003, Sillimanite minerals, in Industrial minerals annual review supplement: London, United Kingdom, Mining Journal Ltd. CD-ROM.

Kyanite—geology

- Deposits of micaceous schist and gneiss in the Appalachian Mountains area and in Idaho
- Aluminous gneiss in southern California

Fig. 1. Kyanite, andalusite, sillimanite, and synthetic mullite production.



Manganese

Manganese—introduction

- Mn
- Harder and more brittle than iron
- Reactive chemically, and decomposes cold water slowly
- Latin word "magnes" meaning “magnet", or "magnesia nigri" meaning "black magnesia"
- Critical mineral

Manganese—properties

- Steel, pig iron, Mn improves the rolling and forging qualities, strength, toughness, stiffness, wear resistance, hardness, and hardenability

Manganese—uses

- dry cell batteries
- "decolorize" glass that is colored green by impurities of iron
- glass an amethyst color
- preparation of oxygen and chlorine
- drying black paints
- permanganate is a powerful oxidizing agent
- plant fertilizers and animal feed,
- coloring agent in bricks
- dioxide is used in the preparation of oxygen, chlorine
- utilization of vitamin B1

Manganese—uses

- Construction, 28%
- Machinery, 13%
- Transportation,12%
- Other iron and steel applications, 47%

Manganese—production

Salient Statistics—United States:[1]	2013	2014	2015	2016	2017[e]
Production, mine	—	—	—	—	—
Imports for consumption:					
Manganese ore	558	387	441	282	310
Ferromanganese	335	365	292	229	300
Silicomanganese[2]	329	448	301	264	370
Exports:					
Manganese ore	1	1	1	1	2
Ferromanganese	2	6	5	7	9
Silicomanganese	6	3	1	2	8
Shipments from Government stockpile excesses[3]					
Manganese ore	—	—	—	—	—
Ferromanganese	1	18	32	42	11
Consumption, reported:[4]					
Manganese ore	523	508	451	410	390
Ferromanganese	368	360	344	342	360
Silicomanganese	152	146	138	139	150
Consumption, apparent, manganese[5]	801	834	693	538	660
Price, average, 46% to 48% Mn metallurgical ore, dollars per metric ton unit, contained Mn:					
Cost, insurance, and freight (c.i.f.), U.S. ports[e]	4.61	4.49	3.53	3.41	4.40
China spot market (c.i.f.)	5.29	4.72	3.22	4.48	[6]5.88
Stocks, producer and consumer, yearend:[4]					
Manganese ore	217	189	187	207	200
Ferromanganese	27	23	21	21	22
Silicomanganese	6	10	21	10	10
Net import reliance[7] as a percentage of apparent consumption	100	100	100	100	100

Recycling: Manganese was recycled incidentally as a constituent of ferrous and nonferrous scrap; however, scrap recovery specifically for manganese was negligible. Manganese is recovered along with iron from steel slag.

USGS Mineral Yearbooks
Thousand metric tons

Manganese—production

World Mine Production and Reserves (manganese content): Reserves for Australia, China, Gabon, Ghana, and India were revised based on data reported by the Governments of those countries.

	Mine production		Reserves[10]
	2016	2017[e]	
United States	—	—	—
Australia	2,240	2,200	[11]94,000
Brazil	1,080	1,200	120,000
China	2,330	2,500	48,000
Gabon	1,620	1,600	20,000
Ghana	553	550	13,000
India	745	790	34,000
Kazakhstan, concentrate	212	230	5,000
Malaysia	266	270	NA
Mexico	206	220	5,000
South Africa	5,300	5,300	200,000
Ukraine, concentrate	425	380	140,000
Other countries	681	760	Small
World total (rounded)	15,700	16,000	680,000

World Resources: Land-based manganese resources are large but irregularly distributed; those in the United States are very low grade and have potentially high extraction costs. South Africa accounts for about 78% of the world's identified manganese resources, and Ukraine accounts for about 10%.

Gabon (Africa), Mexico, Morocco, Australia)

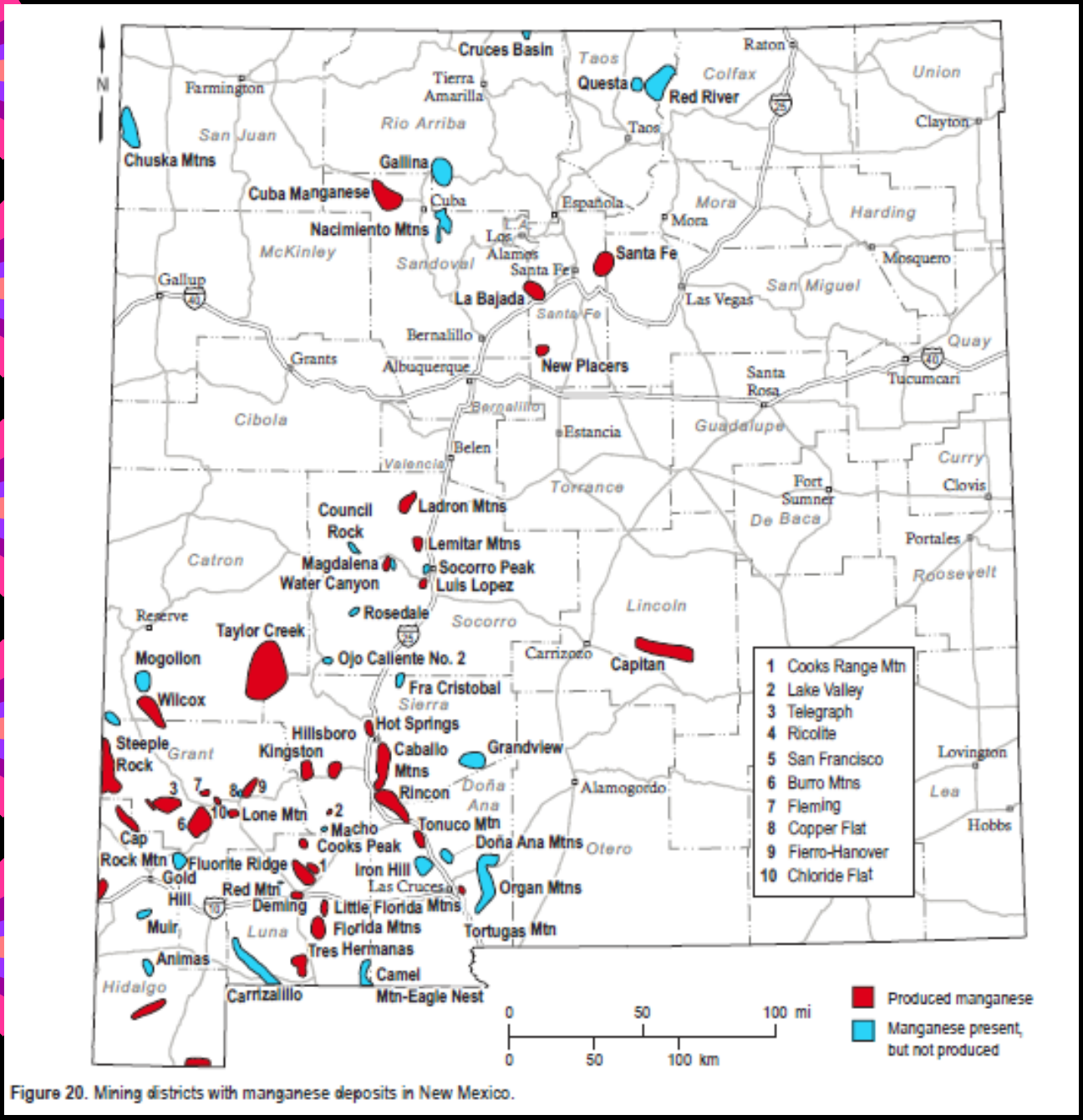


Figure 20. Mining districts with manganese deposits in New Mexico.

McLemore and Austin (2017)

Manganese—substitutions

- None
- Mn is a strategic metal
- Resources in U.S. minimal, low grade, high cost

Manganese—mineralogy

- pyrolusite - MnO_2
- manganite - $MnO(OH)$,
- rhodochrosite - $MnCO_3$
- psilomelane - $BaMnMn_8(OH)_4$

Manganese—geology

- Marine chemical sedimentary deposits
  - Chemical precipitates
  - Nikopol and Tchiatoura in Russia, Kalahari in S. African, Groote Elyandt in Australia
- Residual deposits
  - Alteration or concentration of Mn by weathering
  - Nsuta in Ghana, Amapa in Brazil, Moanda in Gabon, US Appalachians

Manganese—geology

- Other deposits not economic
  - Epithermal Mn
  - Carbonate-hosted Mn
  - Metamorphic
  - Submarine lava flows
  - Ocean floor nodules (Mn, Co, Ni, Cu)

Perlite

Perlite—introduction

- Volcanic siliceous glass
- Rhyolite composition
- Commercial perlite must expand
- Vitreous, pearly luster
- Inert
- 2-5% water allows it to expand similar to popcorn above 871 degrees C
- Gray, white, black, but when expanded-white

http://www.perlite.net/

Perlite—uses

- Building construction products, 69%
- Horticultural aggregate,12%
- Filter aid, 8%
- Fillers, 7%
- Other, 4%

Perlite—production

Salient Statistics—United States:	2013	2014	2015	2016	2017e
Mine production, crude ore	471	462	488	513	520
Sold or used, processed crude perlite	419	462	444	437	455
Imports for consumption[1]	156	144	143	188	160
Exports[1]	52	36	30	21	25
Consumption, apparent[2]	523	570	557	604	590
Price, average value, dollars per ton, f.o.b. mine	57	55	60	64	64
Employment, mine and mill, number	117	119	142	135	140
Net import reliance[3] as a percentage of apparent consumption	20	19	20	28	23

Recycling: Not available.

- Thousand metric tons
- New Mexico leading state
- Turkey, Greece, Italy, Russia, Australia, South Africa

Perlite—production

World Processed Perlite Production and Reserves: Reserves for Greece were revised based on information from official Government sources.

	Production		Reserves[4]
	2016[e]	2017[e]	
United States	[5]513	[5]520	50,000
China	1,800	1,800	NA
Greece	1,490	1,550	120,000
Hungary	30	50	28,000
Iran	60	60	NA
Mexico	28	40	NA
Turkey	950	1,000	57,000
Other countries	115	120	NA
World total (rounded)	5,000	5,100	NA

World Resources: Insufficient information is available to make reliable estimates of resources in perlite-producing countries.

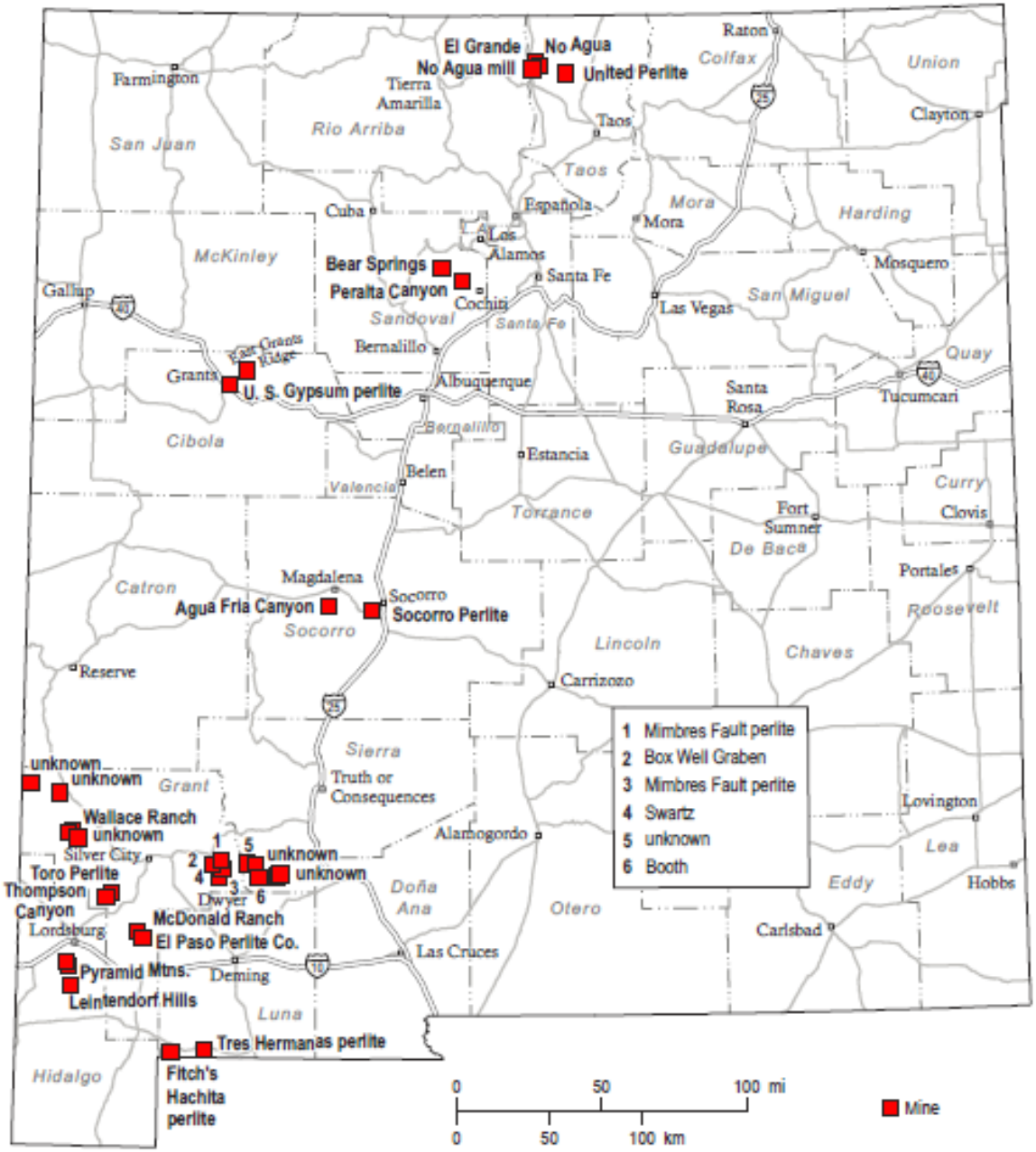
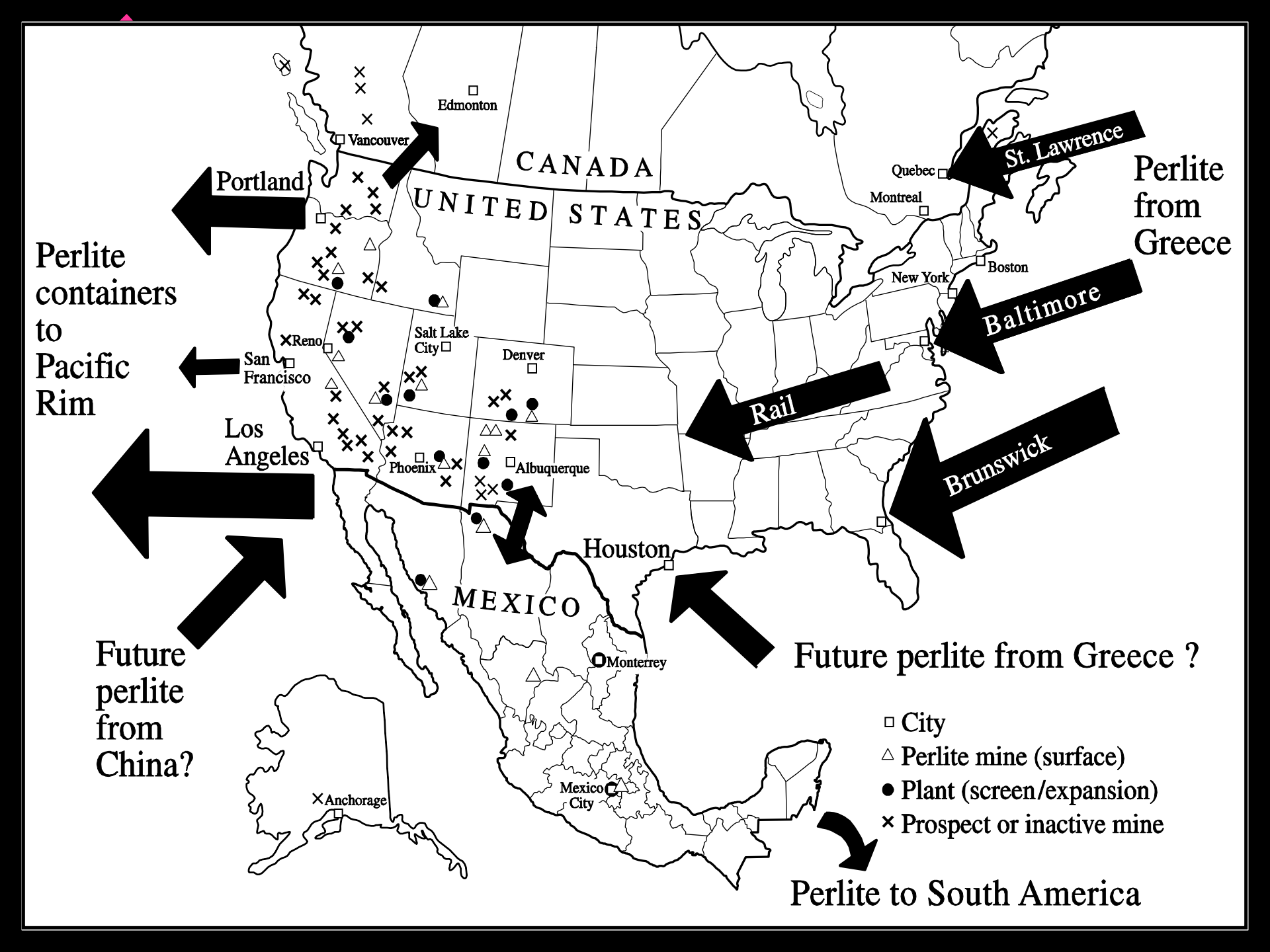


Figure 24. Perlite occurrences and mines in New Mexico.


Edmonton
Vancouver
CANADA
UNITED STATES
Portland
Perlite containers to Pacific Rim
San Francisco
Reno
Salt Lake City
Denver
Los Angeles
Phoenix
Albuquerque
Houston
MEXICO
Monterrey
Mexico City
Anchorage
Future perlite from China?
Future perlite from Greece ?
Perlite to South America
Quebec
Montreal
St. Lawrence
Perlite from Greece
Boston
New York
Baltimore
Rail
Brunswick
City
Perlite mine (surface)
Plant (screen/expansion)
Prospect or inactive mine

Perlite—substitutions

- Diatomite
- Expanded clay and shale
- Pumice
- Slag
- Vermiculite

Perlite—geology

- Volcanic fields
- Grants perlite quarry (U.S. Gypsum)

Nitrogen

Nitrogen—introduction

- Gas
- 78.1% of the atmosphere
- Essential element of life
- Obtained by liquefaction and fractional distillation
- Inert

Nitrogen as ammonia—uses

- Fertilizer (haber process), 89%
  - Nitrogen-phosphorus-potassium (NPK) fertilizers
- Nitric acid (ostwald process)
- Produce plastics
- Synthetic fibers and resins
- Explosives
- Annealing stainless steel and other steel mill products
- Numerous other chemical compounds.

Nitrogen as gas or liquid—uses

- Produce ammonia
- Gas mixtures
- Refrigerant both for the immersion freezing of food products and for transportation of foods
- Build up pressure in wells to force crude oil upward

Nitrogen as ammonia—production

Salient Statistics—United States:	2013	2014	2015	2016	2017[e]
Production	[1]9,170	[1]9,330	[1]9,590	[1]10,200	10,500
Imports for consumption	4,960	4,150	4,320	3,840	3,300
Exports	196	111	93	182	530
Consumption, apparent[2]	13,900	13,300	13,700	13,900	13,300
Stocks, producer, yearend	240	280	420	400	410
Price, dollars per short ton, average, f.o.b. Gulf Coast[3]	541	531	481	267	240
Employment, plant, number[e]	1,200	1,200	1,200	1,300	1,500
Net import reliance[4] as a percentage of apparent consumption	34	30	30	26	21

Recycling: None.

thousand metric tons of contained nitrogen

World Ammonia Production and Reserves:

	Plant production	
	2016	2017e
United States	10,200	10,500
Algeria	1,130	1,200
Australia	1,300	1,300
Belarus	1,060	1,100
Brazil	1,000	1,000
Canada	4,140	4,100
China	46,000	46,000
Egypt	1,800	2,000
France	2,600	2,600
Germany	2,500	2,500
India	10,800	11,000
Indonesia	5,000	5,000
Iran	2,640	2,700
Malaysia	1,460	1,500
Mexico	1,100	1,100
Netherlands	2,300	2,300
Oman	1,700	1,700
Pakistan	2,600	2,600
Poland	2,200	2,200
Qatar	3,050	3,000
Russia	12,500	13,000
Saudi Arabia	4,100	4,100
Trinidad and Tobago	4,910	4,900
Ukraine	1,800	1,800
Uzbekistan	1,200	1,200
Venezuela	1,000	1,000
Vietnam	1,100	1,100
Other countries	13,100	13,100
World total (rounded)	144,000	150,000

Nitrogen as ammonia—production

thousand metric tons of contained nitrogen

Nitrogen as ammonia—production

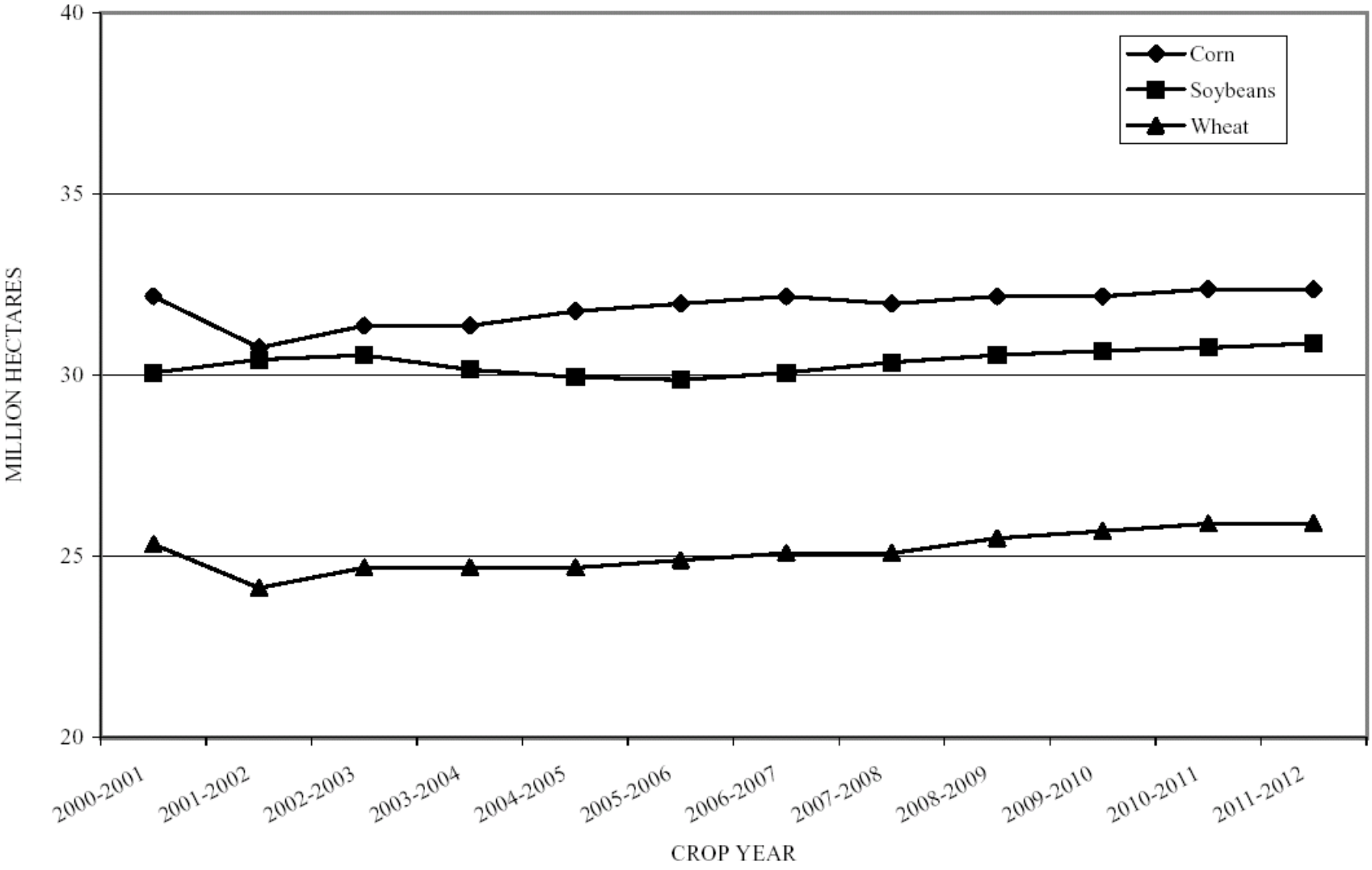
TABLE 3
MAJOR DOWNSTREAM NITROGEN COMPOUNDS
PRODUCED IN THE UNITED STATES 1/ 2/

(Thousand metric tons)

Compound	2000	2001 p/
Urea:		
Gross weight	6,910 r/	6,390
Nitrogen content	3,170 r/	2,930
Ammonium phosphates: e/ 3/		
Gross weight	15,900 r/	14,700
Nitrogen content	2,550 r/	2,280
Ammonium nitrate:		
Gross weight	6,800 r/	6,440
Nitrogen content	2,310 r/	2,180
Nitric acid:		
Gross weight	7,690 r/	7,100
Nitrogen content	1,690 r/	1,560
Ammonium sulfate: 4/		
Gross weight	2,600	2,320
Nitrogen content	552	492

See footnotes at end of table.

FIGURE 6
PROJECTED PLANTED ACREAGE



Source: U.S. Department of Agriculture.

Nitrogen as ammonia—transportation

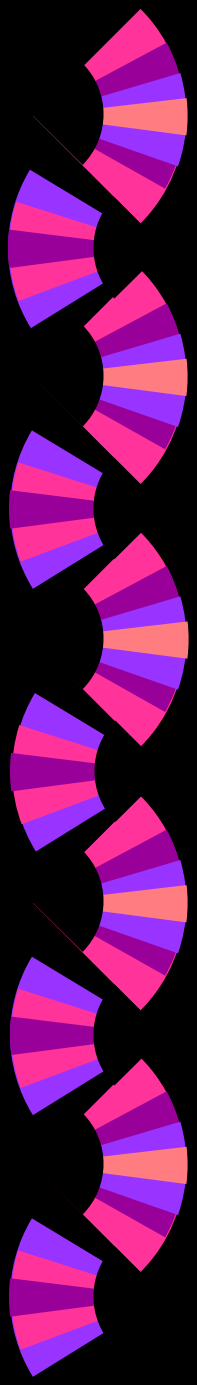
- Refrigerated barge
- Rail
- Pipeline
- Truck

Nitrogen—geology

- Natural gas fields Texas, Oklahoma, Louisiana
- Atmosphere
- Ammonia produced when coal is distilled (coke ovens)

Nitrates—geology

- Guano deposits in caves
- Chile natural sodium nitrate (unique)
  - Caliche rich in nitrate
  - Driest desert in world 0.04 inch/yr allowed slow buildup of salines since the miocene
  - NaCl, SO4, borates, iodine
  - Guggenheim process



Phosphate

Phosphate—introduction

- Essential element for plant and animal nutrition
- Greek word "phosphoros" meaning "bringer of light"
- Discovered in 1669 by hennig brand, who prepared it from urine

Phosphate—uses

- Phosphoric acid and superphosphoric acid, 90%
  - Fertilizers
  - Animal feed supplements
- Phosphorus compounds
  - Industrial
  - Food-additive
- Safety matches, pyrotechnics, incendiary shells, smoke bombs, tracer bullets
- Pesticides
- Bone-ash, calcium phosphate, is used to produce fine chinaware

Phosphate—production

Salient Statistics—United States:	2013	2014	2015	2016	2017[e]
Production, marketable	31,200	25,300	27,400	27,100	27,700
Used by producers	28,800	26,700	26,200	26,700	26,700
Imports for consumption	3,170	2,380	1,960	1,590	2,100
Exports	—	—	—	—	—
Consumption, apparent[1]	31,900	29,100	28,100	28,200	28,800
Price, average value, dollars per ton, f.o.b. mine[2]	91.11	78.59	72.41	76.90	75.00
Stocks, producer, yearend	9,000	5,880	6,730	7,180	7,500
Employment, mine and beneficiation plant, number[e]	2,170	2,100	2,000	2,000	2,000
Net import reliance[3] as a percentage of apparent consumption	3	18	4	4	6

Recycling: None.

- Thousand metric tons
- Florida, North Carolina, Idaho, Utah

Phosphate—production

	Mine production		Reserves[4]
	2016	2017[e]	
United States	27,100	27,700	1,000,000
Algeria	1,270	1,300	2,200,000
Australia	3,000	3,000	[5]1,100,000
Brazil	5,200	5,500	1,700,000
China[6]	135,000	140,000	3,300,000
Egypt	5,000	5,000	1,300,000
Finland	940	950	1,000,000
India	2,000	1,800	65,000
Israel	3,950	4,000	74,000
Jordan	7,990	8,200	1,300,000
Kazakhstan	1,500	1,600	260,000
Mexico	1,700	2,000	30,000
Morocco and Western Sahara	26,900	27,000	50,000,000
Peru	3,850	3,900	400,000
Russia	12,400	12,500	700,000
Saudi Arabia	4,200	4,500	1,400,000
Senegal	2,200	2,200	50,000
South Africa	1,700	1,800	1,500,000
Syria	—	100	1,800,000
Togo	850	1,000	30,000
Tunisia	3,660	3,700	100,000
Vietnam	2,800	3,000	30,000
Other countries	1,950	1,940	900,000
World total (rounded)	255,000	263,000	70,000,000

Thousand metric tons

Phosphate—substitutions

- Bone phosphate of lime

Phosphate—geology

- Marine sedimentary deposits
  - phosphorites Precambrian to Recent, on every continent
  - beds few cm thick of grains of cryptocrystalline carbonate fluorapatite (collophane, francolite)
- Ocean
- Carbonatites

Phosphate—mineralogy

- Apatite Ca10(PO4,CO3)6(F,OH,Cl)2
- Wavellite Al3(PO4)2(OH)3.5H2O
- Crandallite CaAL3(PO4)2(OH)5.H2O
- Millisite ((Na, K)CaAl6(PO4)4)(OH)9.3H2O

Phosphate—environmental considerations

- Uranium is a by-product
- Radioactive
- Radon

Potash

Potash—introduction

- K not found naturally as an element
- Compounds
- 7th most abundant element
- End of the 19th century, potash was made from hardwood trees
- Critical mineral

Potassium—properties

- Most reactive and electropositive of metals
- Soft
- Rapidly oxidizes in air
- Catches fire spontaneously on water

Potassium—forms

- Potassium chloride (KCl, sylvite),
- Potassium sulfate (K2SO4 or sulfate of potash (SOP)), ussually manufactured
- Magnesium sulfate [K2SO4C2MgSO4, langbeinite
- Muriate of potash (MOP), mixture of KCl and NaCl
- Potassium nitrate (KNO3 or saltpeter)
- Sodium-potassium nitrate (NaNO3 + KNO3 or Chilean saltpeter

Potash—uses

- Fertilizers
- Alloy of sodium and potassium (nak) is used as a heat-transfer medium
- Soap (lye)
- Oil-well drilling muds
- Metal electroplating
- Snow and ice melting
- Water softening

Potash—uses

- Glass for television and computer monitor tube production
- Alkaline batteries
- Food products
- Pharmaceutical preparations
- Photography
- Some fire extinguishers
- Animal feed supplements
- Catalyst for synthetic rubber manufacture

Potash—production

Salient Statistics—United States:	2013	2014	2015	2016	2017[e]
Production, marketable[1]	960	850	740	500	480
Sales by producers, marketable[1]	880	930	620	600	510
Imports for consumption	4,650	4,970	5,000	4,550	5,700
Exports	255	100	106	99	100
Consumption, apparent[1, 2]	5,300	5,800	5,500	5,000	6,100
Value, dollars per ton of K_2O, average, all products, f.o.b. mine[3]	715	735	880	680	790
Employment, number, mine and mill	1,600	1,400	1,300	1,150	900
Net import reliance[4] as a percentage of apparent consumption	82	85	87	90	92

Recycling: None.

- thousand metric tons of K2O equivalent
- New Mexico leading state, also Utah

Potash—production

	Mine production		Reserves[5]	
	2016	2017[e]	Recoverable ore	K_2O equivalent
United States[1]	500	480	1,000,000	210,000
Belarus	6,180	6,400	3,300,000	750,000
Brazil	301	300	310,000	24,000
Canada	10,800	12,000	4,200,000	1,000,000
Chile	1,200	1,200	NA	150,000
China	6,200	6,200	NA	360,000
Germany	2,800	2,900	NA	150,000
Israel	2,050	2,200	NA	[6]270,000
Jordan	1,200	1,300	NA	[6]270,000
Russia	6,480	7,200	3,000,000	500,000
Spain	670	680	NA	44,000
United Kingdom	450	450	NA	40,000
Other countries	480	500	250,000	90,000
World total (rounded)	39,300	42,000	NA	3,900,000

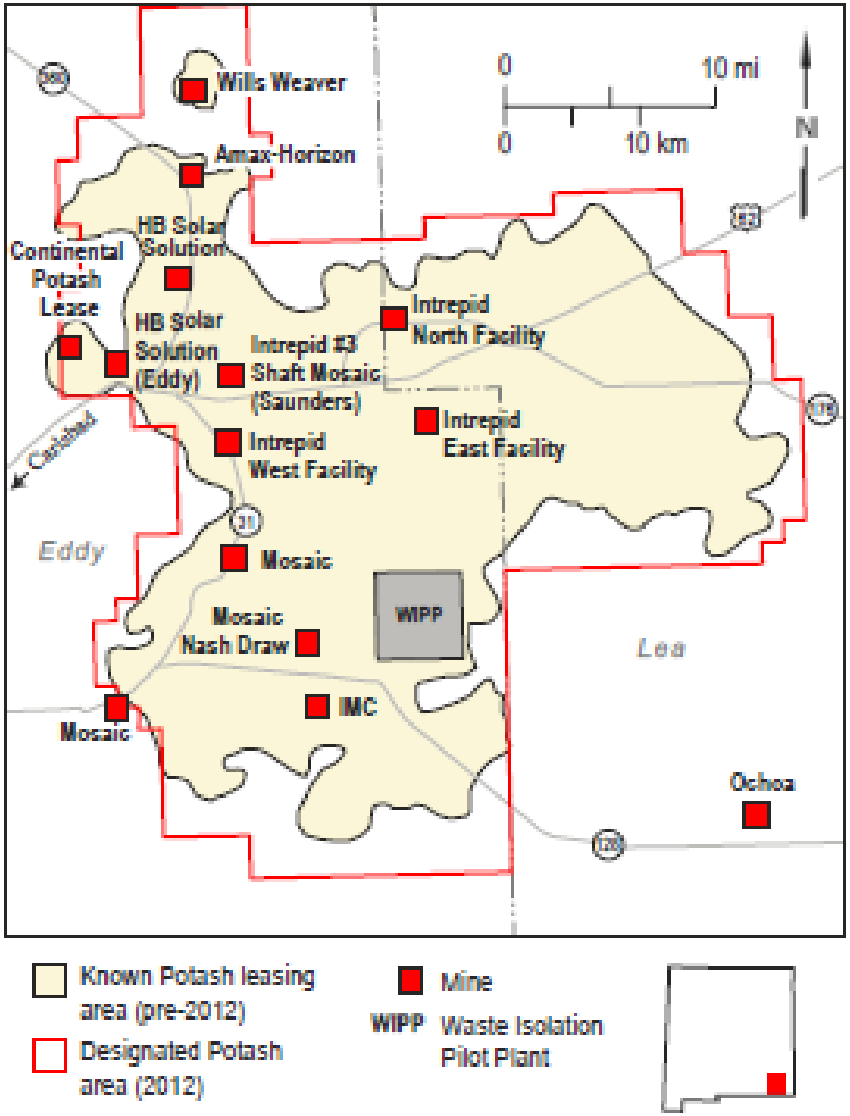


Figure 26. Potash facilities in Eddy and Lea Counties, southeastern New Mexico, showing the general outline of the Designated Potash Area (DPA) (after Barker and Austin, 1999). WIPP=Waste Isolation Pilot Plant.

Potash—transportation

- Railroad
- Ships
- Truck

Potash—geology

- Evaporate deposits
- Brines
  - Great Salt Lake

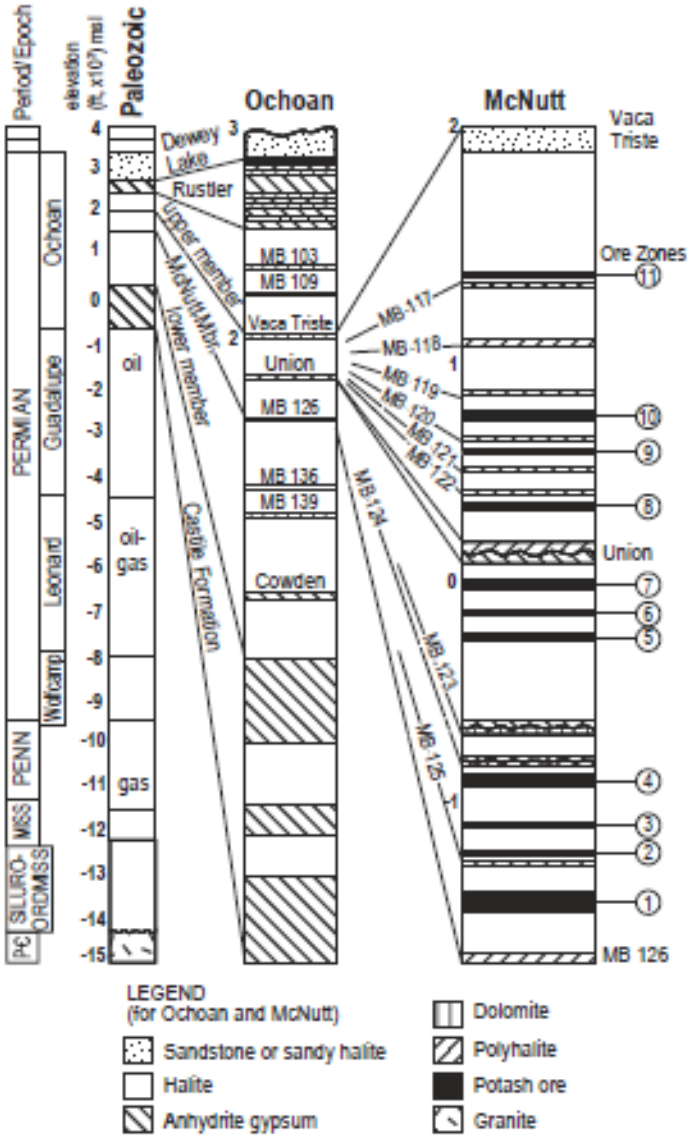
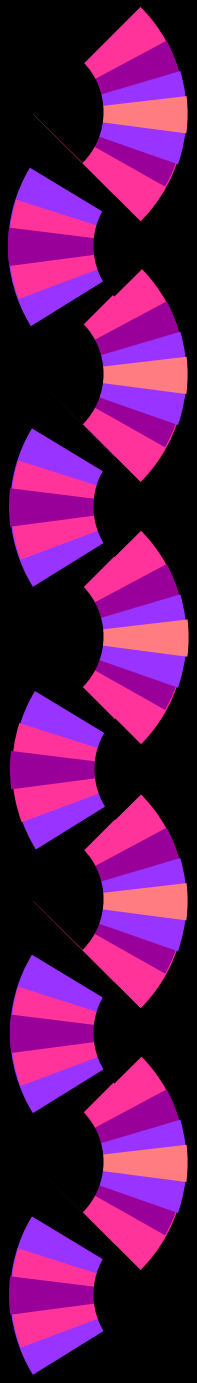


Figure 28. Regional stratigraphic column with expanded sections of the Ochoan evaporite and McNutt Member of the Salado (after Griswold, 1982 and Barker and Austin, 1999). Numbers 1–11 are ore zones. MB = marker bed.

Underground operations at IMC potash mine, Carlsbad.

Potash ore is processed by flotation, heavy media separation, dissolution-recrystallization, and washing.



Salt

Salt—introduction

- NaCl
- Table salt
- Essential to life
- Salt was used as a preservative, tanning leather, stock, mining
- Salt was used to preserve Egyptian mummies

Salt—introduction

- Trade in salt was very important; salt was valuable enough to be used as currency in some areas.
- The Latin phrase "salarium argentum," "salt money," referred to part of the payment made to Roman soldiers.

http://www-geology.ucdavis.edu/~gel115/salt.html

Salt—introduction

- Greek worshippers consecrated salt in their rituals
- In the Old and New Testaments, covenants were sealed with salt
- Catholic Church used salt in purifying rituals
- Buddhist believed salt repeals evil spirits
- Pueblo people worship the Salt Mother

The star of David used to crystallise salt in salt pans in Mexico, La Concordia - from "Maya Salt Production and Trade - Antony P. Andrews " courtesy Gertrude Blom.

http://salt.org.il/frame_rel.html

Salt and Silver Processing

- Patio process developed in 1557 in Pachuca, Hidalgo, Mexico
- Silver ores crushed in arrastras to a fine slime
- Mixed with salt, water, copper sulfate, mercury
- Spread onto a patio and allowed to dry in the sun
- Silver could then amalgamate with mercury and thus be recovered

Salt—sold by type in US

- Salt in brine, 52%
- Rock salt, 31%
- Vacuum pan, 10%
- Solar salt, 7%

Salt—uses

- Chemical industry, 42%
- Highway deicing, 36%
- Distributors, 7%
- Industrial, 6%
- Agricultural, 4%
- Food, 3%
- Primary water treatment, 1%
- Other, 1%

Salt—substitutions

- Calcium chloride and calcium magnesium acetate, hydrochloric acid, and potassium chloride can be substituted for salt in deicing, certain chemical processes, and food flavoring, but at a higher cost.

Salt—production

Salient Statistics—United States:[1]	2013	2014	2015	2016	2017[e]
Production	39,900	45,300	45,100	[e]42,000	43,000
Sold or used by producers	43,100	46,000	42,800	[e]38,000	39,000
Imports for consumption	11,900	20,200	21,600	12,100	13,000
Exports	525	935	841	716	1,100
Consumption:					
Apparent[2]	54,500	65,300	63,600	[e]49,400	50,000
Reported	47,600	55,600	52,300	[e]42,000	43,000
Price, average value of bulk, pellets and packaged salt, dollars per ton, f.o.b. mine and plant:					
Vacuum and open pan salt	172.09	180.61	188.87	[e]190.00	190.00
Solar salt	78.04	75.35	82.45	[e]87.00	90.00
Rock salt	47.22	48.11	56.32	[e]50.00	45.00
Salt in brine	8.49	9.08	10.27	[e]10.50	9.40
Employment, mine and plant, number[e]	4,100	4,200	4,200	4,100	4,100
Net import reliance[3] as a percentage of apparent consumption	22	29	33	23	23

Recycling: None.

thousand metric tons

Salt—production

World Production and Reserves:

	Production[e]		Reserves[4]
	2016	2017	
United States[1]	42,000	43,000	Large. Economic and subeconomic deposits of salt are substantial in principal salt-producing countries. The oceans contain a virtually inexhaustible supply of salt.
Australia	11,000	11,000	
Brazil	7,600	7,500	
Canada	14,000	13,000	
Chile	12,000	12,000	
China	67,000	68,000	
France	6,000	6,000	
Germany	12,000	13,000	
India	25,000	26,000	
Mexico	8,800	9,000	
Poland	3,500	3,500	
Spain	4,300	4,300	
Turkey	11,000	11,000	
United Kingdom	5,000	5,000	
Other countries	45,000	45,000	
World total (rounded)	270,000	280,000	

thousand metric tons

Salt—geology

- Marine evaporite salt, potash-bearing bedded salt
- Brines
- Playa lakes
- Salt domes

- Kansas, Louisiana, Michigan, New York, Ohio, Texas, Utah, New Mexico

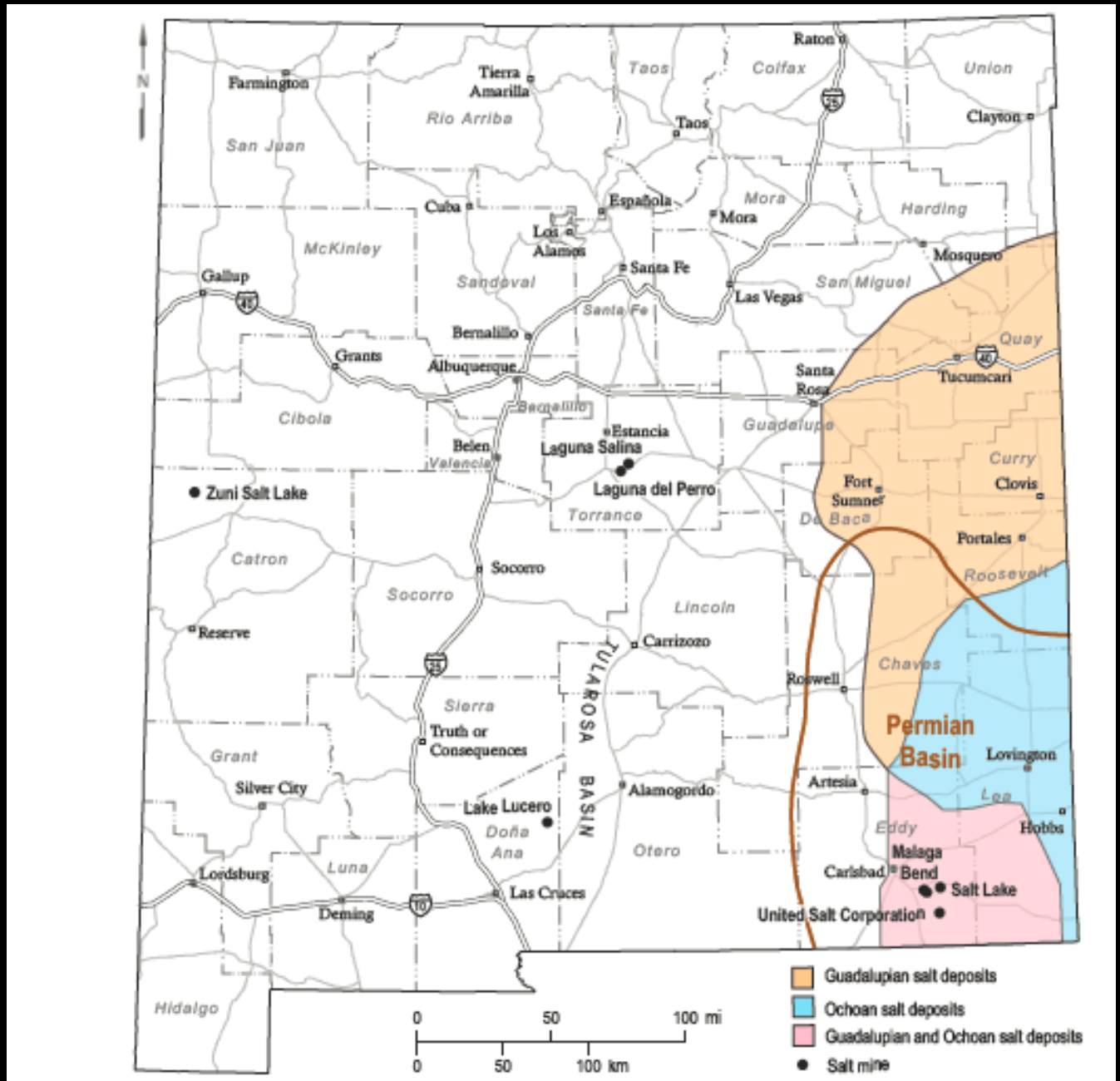


Figure 40. Distribution of major salt deposits and mines in New Mexico. Distribution of salt deposits is from Jones (1974a).

Sulfur

Sulfur—introduction

- S
- Corrosive
- Egyptians used sulfur compounds to bleach fabric as early as 2000 B.C.
- Ancient greeks used sulfur as a disinfectant
- Romans used it in pharmaceutical applications
- Chinese used S in gunpowder in the 13th century

Sulfur—introduction

- Sulfuric acid is an indicator of the condition of a nation's industrial activity
- Most companies are trying to dispose of S, rather than mine it
- Sulfur emissions produces acid rain, other effects

Sulfur—uses

- Sulfuric acid
- Agricultural chemicals (fertilizers)
- Petroleum refining
- Pulp and paper manufacturing
- Sulfur construction materials
- Produce titanium oxide
- Organic and inorganic chemicals

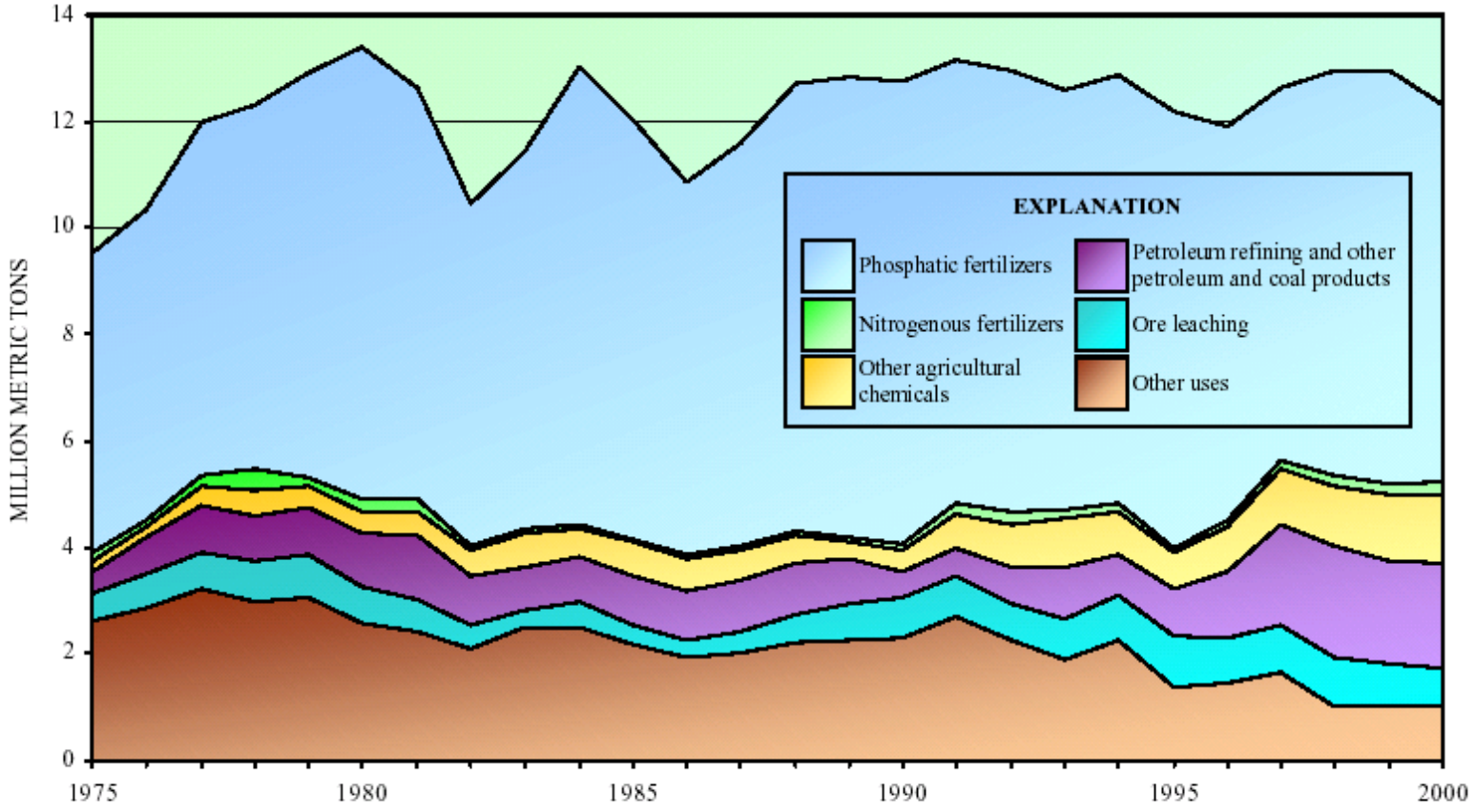


Figure 19. Chart that shows the end uses of sulfur and sulfuric acid. In addition to the uses listed, sulfur and sulfuric acid are consumed in a wide variety of other industries.

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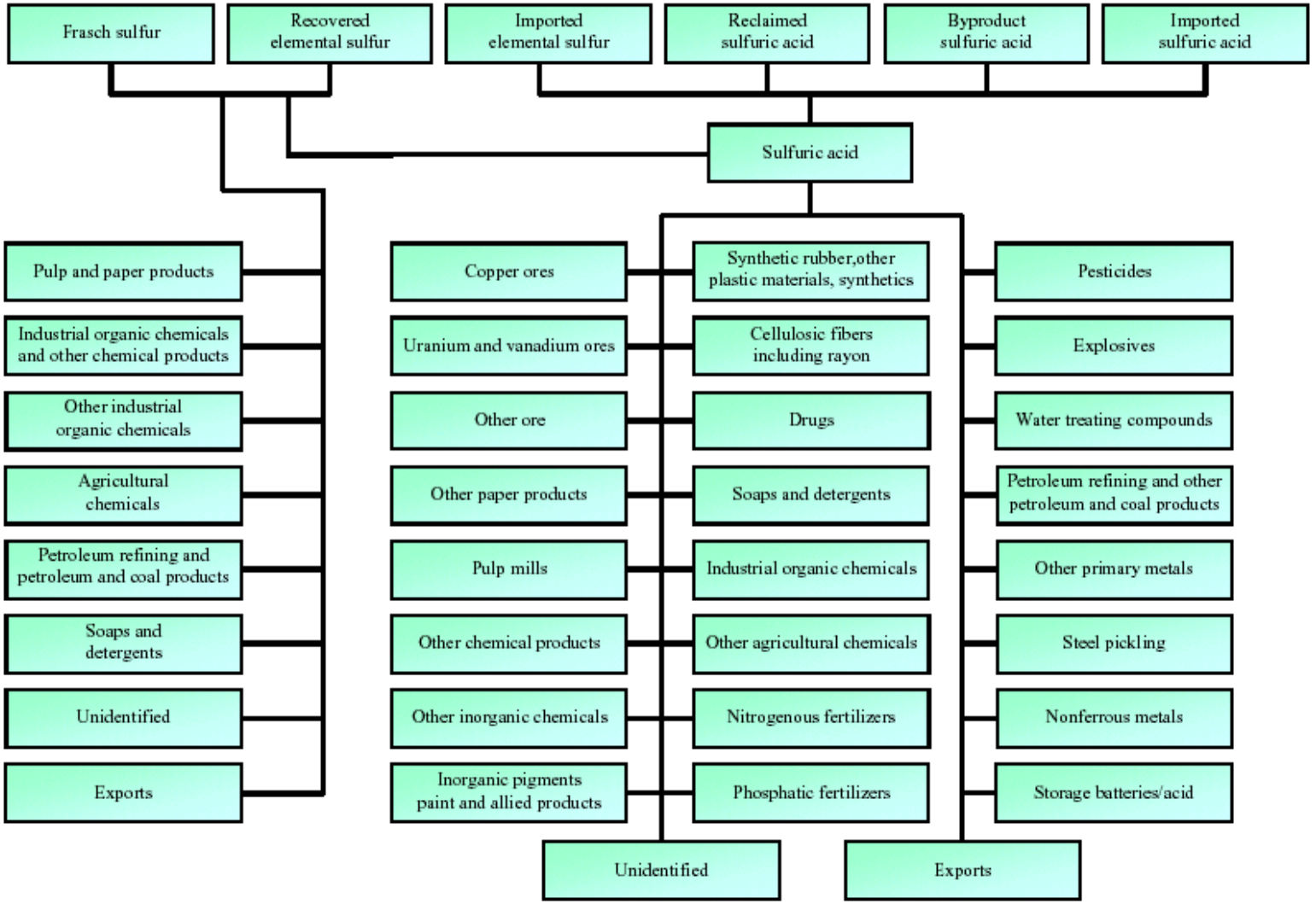

Figure 16. Flow diagram that shows the possible sources of sulfur and some of the possible end-use categories. Some end uses require elemental sulfur, but most require that the sulfur be converted to sulfuric acid before use.

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TABLE 6
SULFUR AND SULFURIC ACID SOLD OR USED IN THE UNITED STATES, BY END USE 1/

(Thousand metric tons, sulfur content)

SIC 3/	End use	Elemental sulfur 2/		Sulfuric acid (sulfur equivalent)		Total	
		2000	2001	2000	2001	2000	2001
102	Copper ores	--	--	671	691	671	691
1094	Uranium and vanadium ores	--	--	2	3	2	3
10	Other ores	--	--	44	26	44	26
26, 261	Pulpmills and paper products	W	--	136	194	136	194
28, 285, 286, 2816	Inorganic pigments, paints and allied products, industrial organic chemicals, other chemical products 4/	75 r/	W	152	158	227 r/	158
281	Other inorganic chemicals	W	W	202	207	202	207
282, 2822	Synthetic rubber and other plastic materials and synthetics	--	--	68	68	68	68
2823	Cellulosic fibers, including rayon	--	--	5	11	5	11
283	Drugs	--	--	2	3	2	3
284	Soaps and detergents	W	W	1	7	1	7
286	Industrial organic chemicals	--	--	82	86	82	86
2873	Nitrogenous fertilizers	--	--	213	188	213	188
2874	Phosphatic fertilizers	--	--	7,110	6,840	7,110	6,840
2879	Pesticides	--	--	14	10	14	10
287	Other agricultural chemicals	1,260	1,120	29	31	1,290	1,150
2892	Explosives	--	--	8	10	8	10
2899	Water-treating compounds	--	--	52	66	52	66
28	Other chemical products	--	--	22	21	22	21
29, 291	Petroleum refining and other petroleum and coal products	1,460	1,960	497	591	1,960	2,550
331	Steel pickling	--	--	16	17	16	17
333	Nonferrous metals	--	--	38	38	38	38
33	Other primary metals	--	--	8	5	8	5
3691	Storage batteries (acid)	--	--	11	13	11	13
	Exported sulfuric acid	--	--	6	2	6	2
	Total identified	2,790	3,080	9,390	9,280	12,200	12,400
	Unidentified	1,190	1,750	237	250	1,430	2,000
	Grand total	3,980	4,830	9,620	9,530	13,600	14,400

Table 4. Estimates of Sulfur Consumption for Fertilizer Products

Phosphate product (per metric ton P_2O_5 content)	Sulfur requirement (metric tons)	Sulfuric acid requirement (metric tons)
Wet process phosphoric acid (WPPA)	0.915	2.80
Single superphosphate (SSP)	0.121	0.37
Triple superphosphate (TSP)	0.314	0.96
Monoammonium phosphate (MAP)	0.493	1.51
Diammonium phosphate (DAP)	0.431	1.32
Ammonium sulfate (AS)	0.242	0.74

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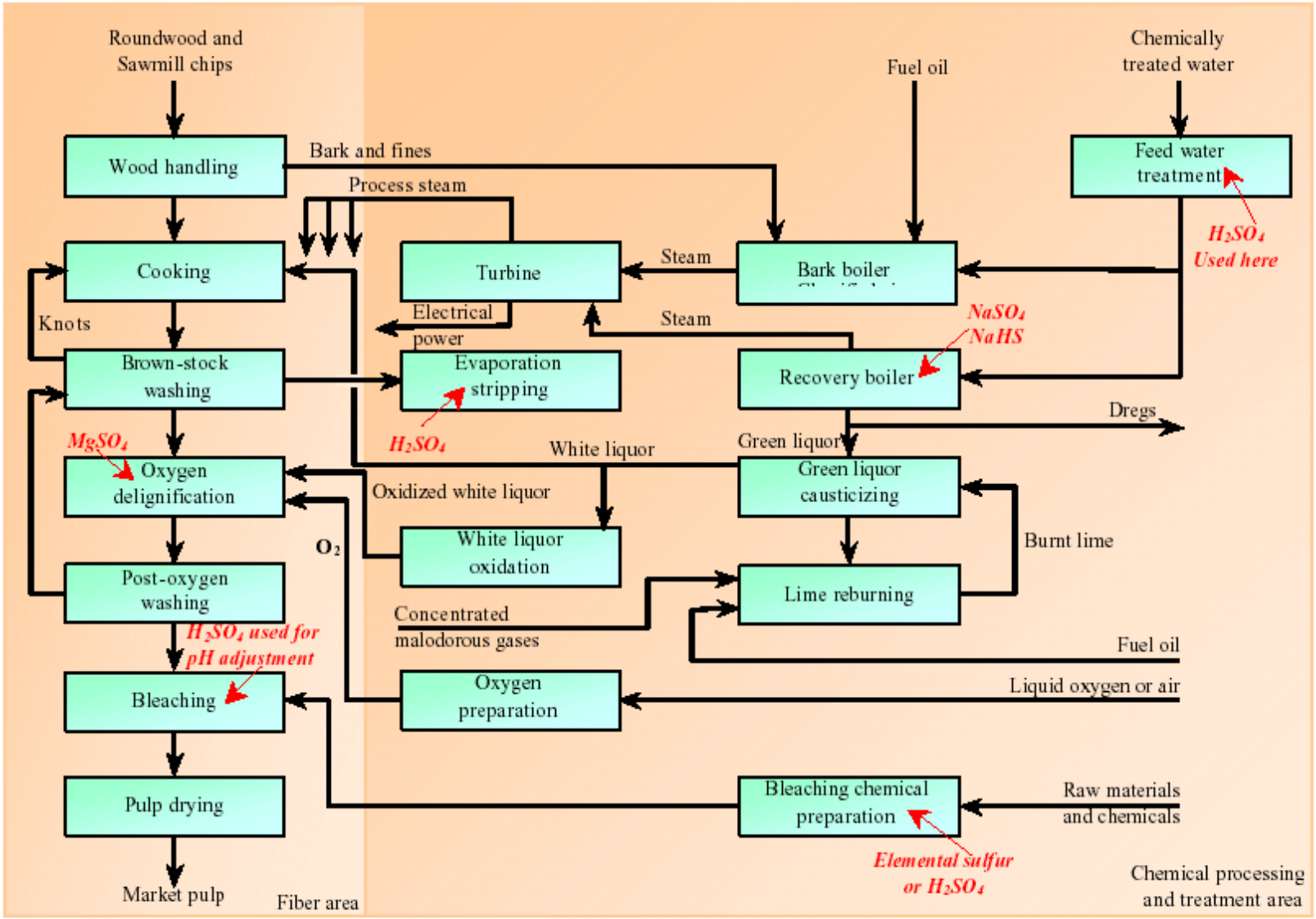

Figure 30. Chart that shows the steps in the Kraft pulp and paper process that use sulfur chemicals.

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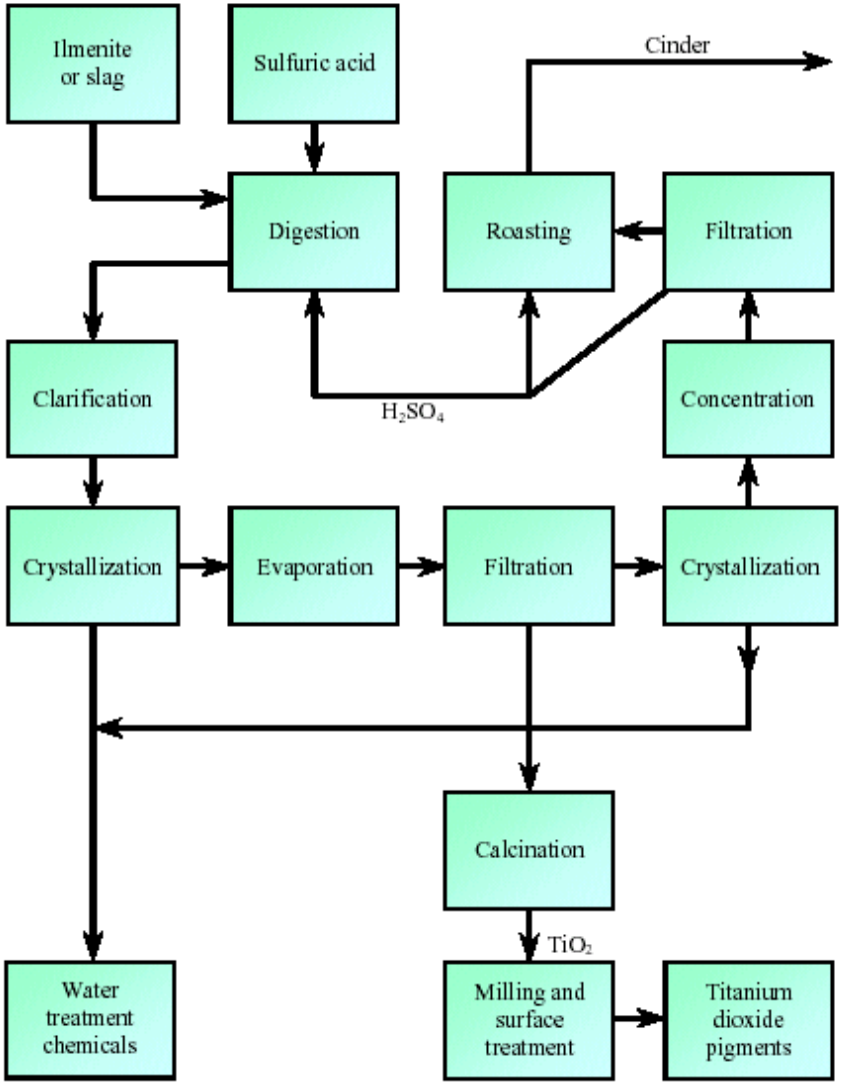

Figure 32. Flow diagram that shows the sulfate process for producing titanium dioxide and its waste acid recycling circuit. H_2SO_4 is sulfuric acid.

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Sulfur—geology

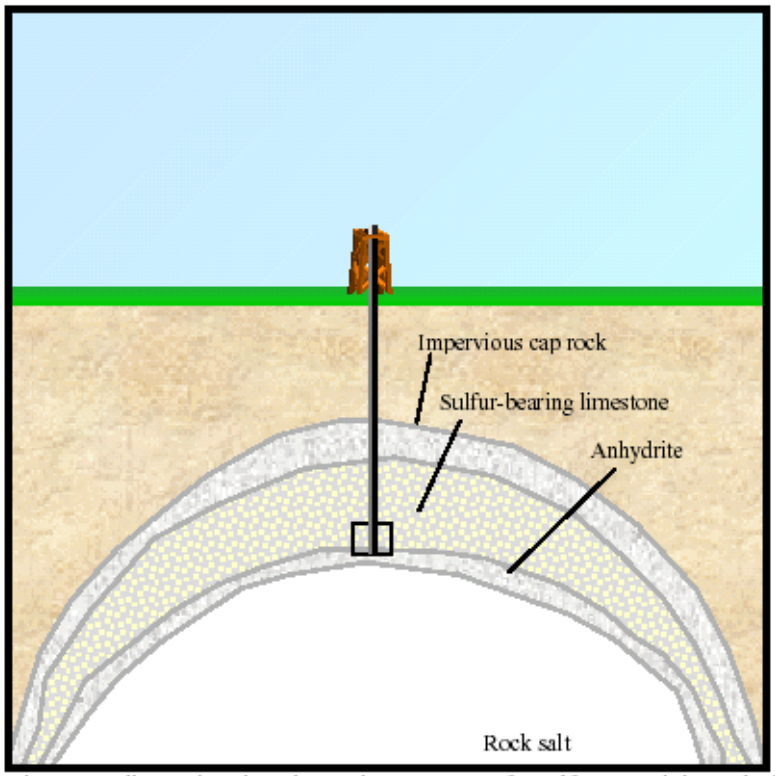
- Byproduct at petroleum refineries and natural gas processing plants
- Byproduct H_2SO_4 from metal smelters
- Volcanic vent deposits fumarolic sulfur
- Brines
- Salt domes
- Epigenetic sulfur deposits are associated with carbonate rocks and karst

Sulfur

- Epigenetic sulfur deposits are associated with carbonate rocks and karst
- Dissolution of gypsum and limestone (karst)
- The S freed by dissolution of gypsum migrates into voids in the limestone

Frasch process of recovering sulfur

- 1894 Dr. Herman Frasch
- Union Sulphur Co. in Calcasieu Parish, La.
- Melting the sulfur underground and pumping it to the surface
- Commercial in 1903



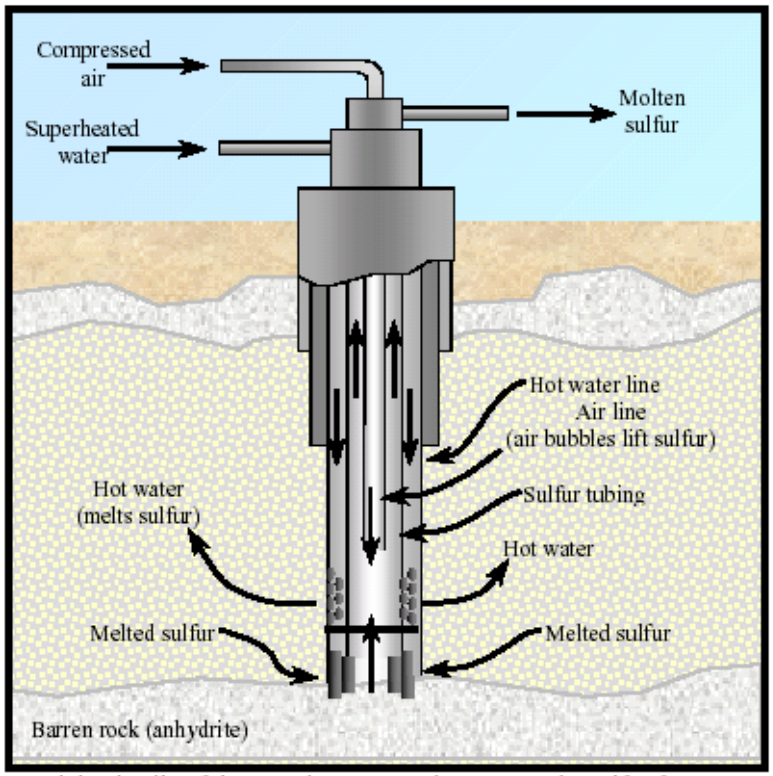


Figure 6. Illustration that shows the structure of a sulfur-containing salt dome and the details of the Frasch pump used to extract the sulfur from underground formations. Superheated water is pumped into the formation to melt the sulfur. The molten sulfur is lifted to the surface with compressed air.

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Sulfur—production

- Sustainable production of necessary sulfur supplies is not in question
- Sulfur recovered for environmental reasons is the predominant source of sulfur worldwide
- Current production exceeds consumption by a relatively small percentage, but environmental regulations are changing that
- The infrastructure is inadequate for transporting the large volumes of sulfur produced in many 3rd world countries
- More S produced in US than any other chemical

Sulfur—production

Salient Statistics—United States:	2013	2014	2015	2016	2017e
Production:					
Recovered elemental	8,590	9,050	8,890	9,070	9,030
Other forms	616	587	646	673	630
Total (rounded)	9,210	9,640	9,540	9,740	9,660
Shipments, all forms	9,200	9,670	9,560	9,750	9,750
Imports for consumption:					
Recovered, elemental[e]	2,990	2,370	2,240	1,820	2,010
Sulfuric acid, sulfur content	972	1,000	1,160	1,050	940
Exports:					
Recovered, elemental	1,770	2,010	1,840	2,050	2,260
Sulfuric acid, sulfur content	54	53	58	58	66
Consumption, apparent, all forms[1]	11,300	11,000	11,000	10,500	10,300
Price, reported average value, dollars per ton of elemental sulfur, f.o.b., mine and (or) plant	68.71	80.07	87.62	37.88	60.00
Stocks, producer, yearend	160	141	138	144	136
Employment, mine and (or) plant, number	2,600	2,600	2,600	2,500	2,400
Net import reliance[2] as a percentage of apparent consumption	19	12	14	7	6

Recycling: Typically, between 2.5 million and 5 million tons of spent sulfuric acid is reclaimed from petroleum refining and chemical processes during any given year.

thousand metric tons

Sulfur—resources

World Production and Reserves:

	Production—All forms		Reserves[3]
	2016	2017[e]	
United States	9,740	9,660	Reserves of sulfur in crude oil, natural gas, and sulfide ores are large. Because most sulfur production is a result of the processing of fossil fuels, supplies should be adequate for the foreseeable future. Because petroleum and sulfide ores can be processed long distances from where they are produced, sulfur production may not be in the country to which the reserves were attributed. For instance, sulfur from Saudi Arabian oil may be recovered at refineries in the United States.
Australia	900	900	
Brazil	530	530	
Canada	5,320	5,300	
Chile	1,800	1,800	
China	17,750	17,800	
Finland	820	820	
Germany	3,800	3,800	
India	3,130	3,200	
Iran	2,200	2,200	
Italy	550	550	
Japan	3,420	3,400	
Kazakhstan	3,120	3,100	
Korea, Republic of	2,430	2,400	
Kuwait	850	850	
Mexico	1,160	1,200	
Netherlands	530	530	
Poland	1,200	1,200	
Qatar	1,900	1,900	
Russia	6,960	7,000	
Saudi Arabia	4,900	4,900	
Turkmenistan	600	600	
United Arab Emirates	5,300	5,300	
Venezuela	700	700	
Other countries	3,200	3,300	
World total (rounded)	83,000	83,000	

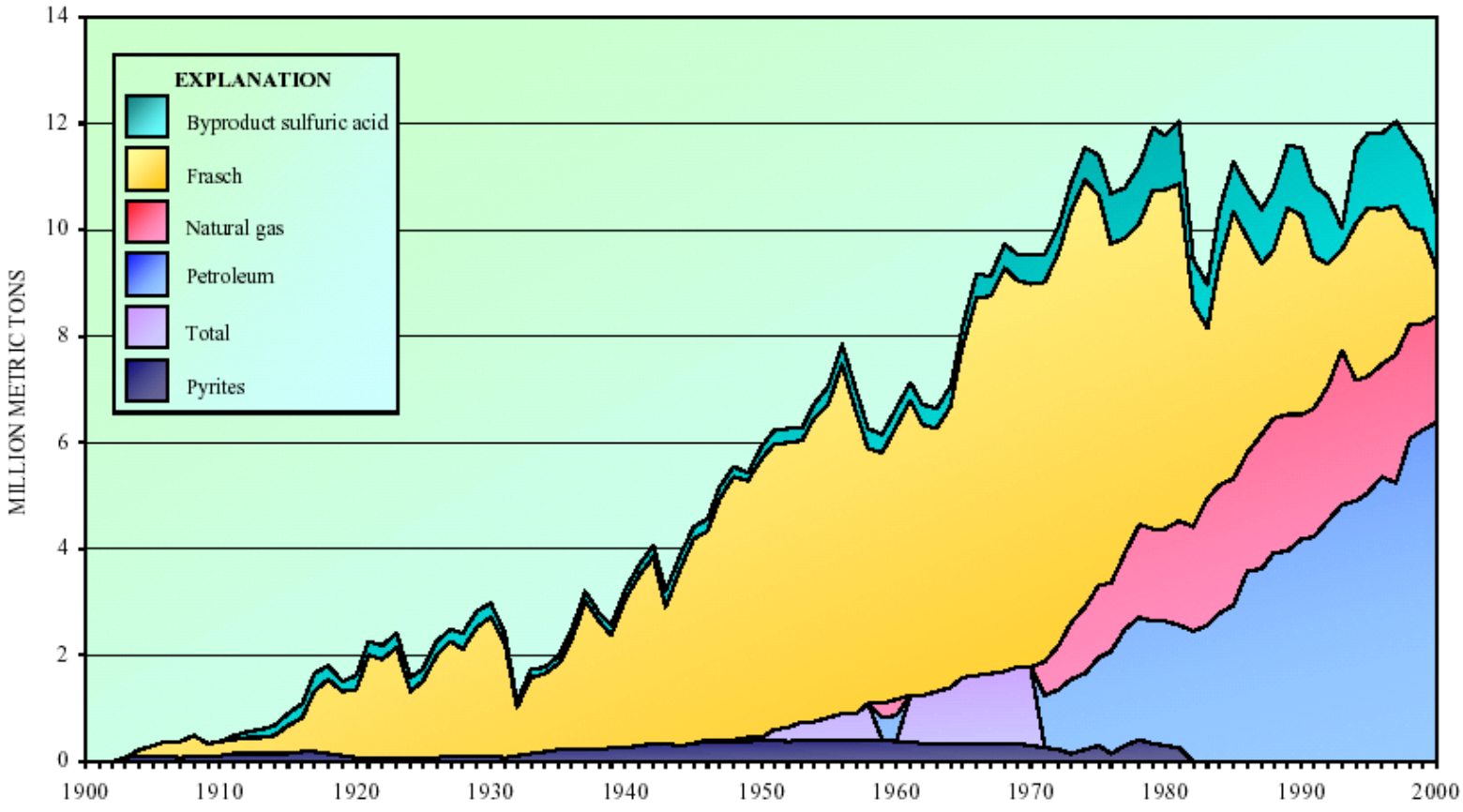

Figure 9. Chart that shows how production of sulfur in all forms has changed over time.

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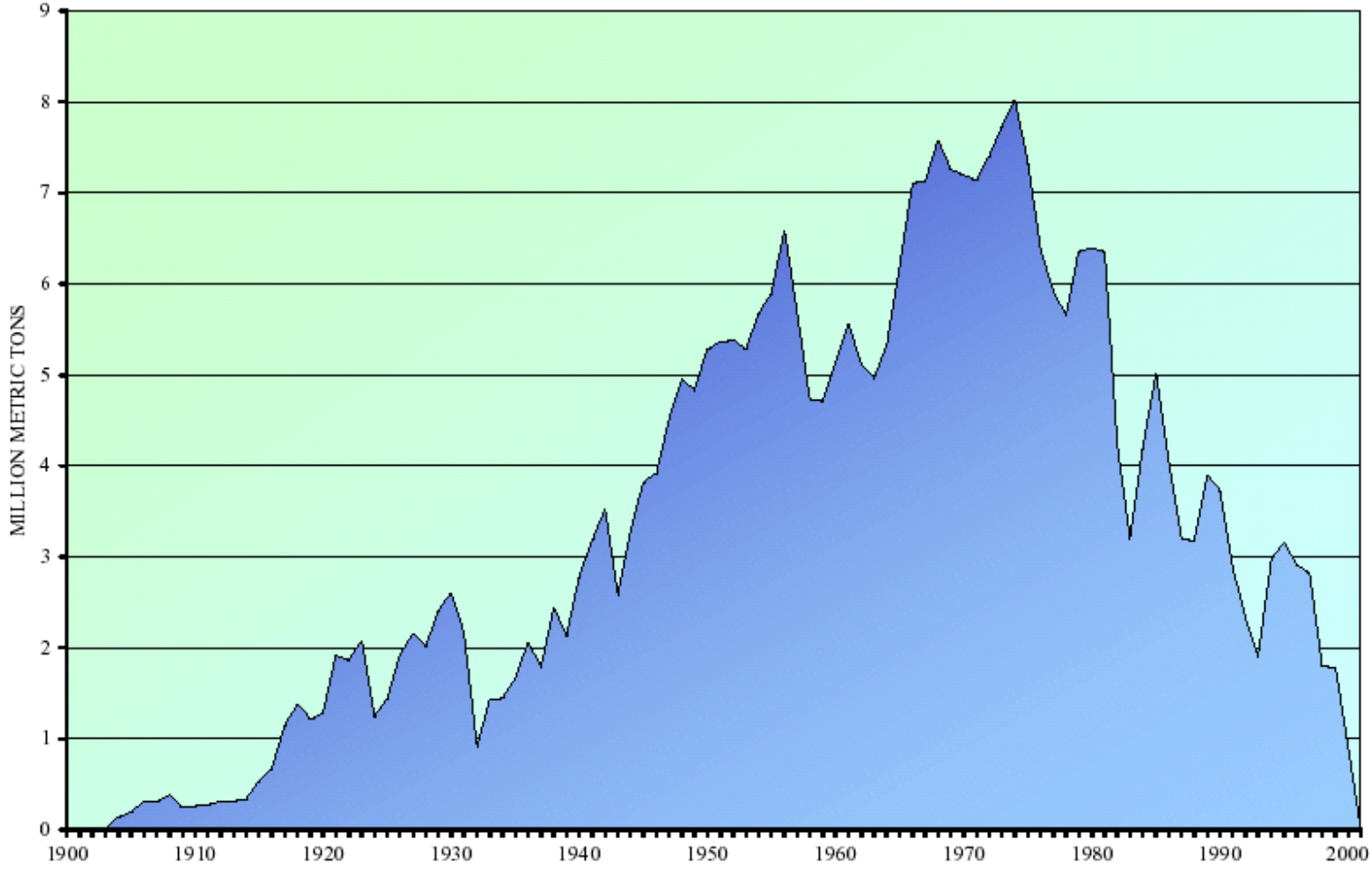

Figure 7. Chart that shows the birth and demise of the Frasch sulfur industry in the United States. Early production data included some native sulfur produced via conventional mining methods, but it was quickly dwarfed by Frasch production. Production peaked in 1974 at about 8 million metric tons. Domestic sulfur mining ceased completely in August 2000.

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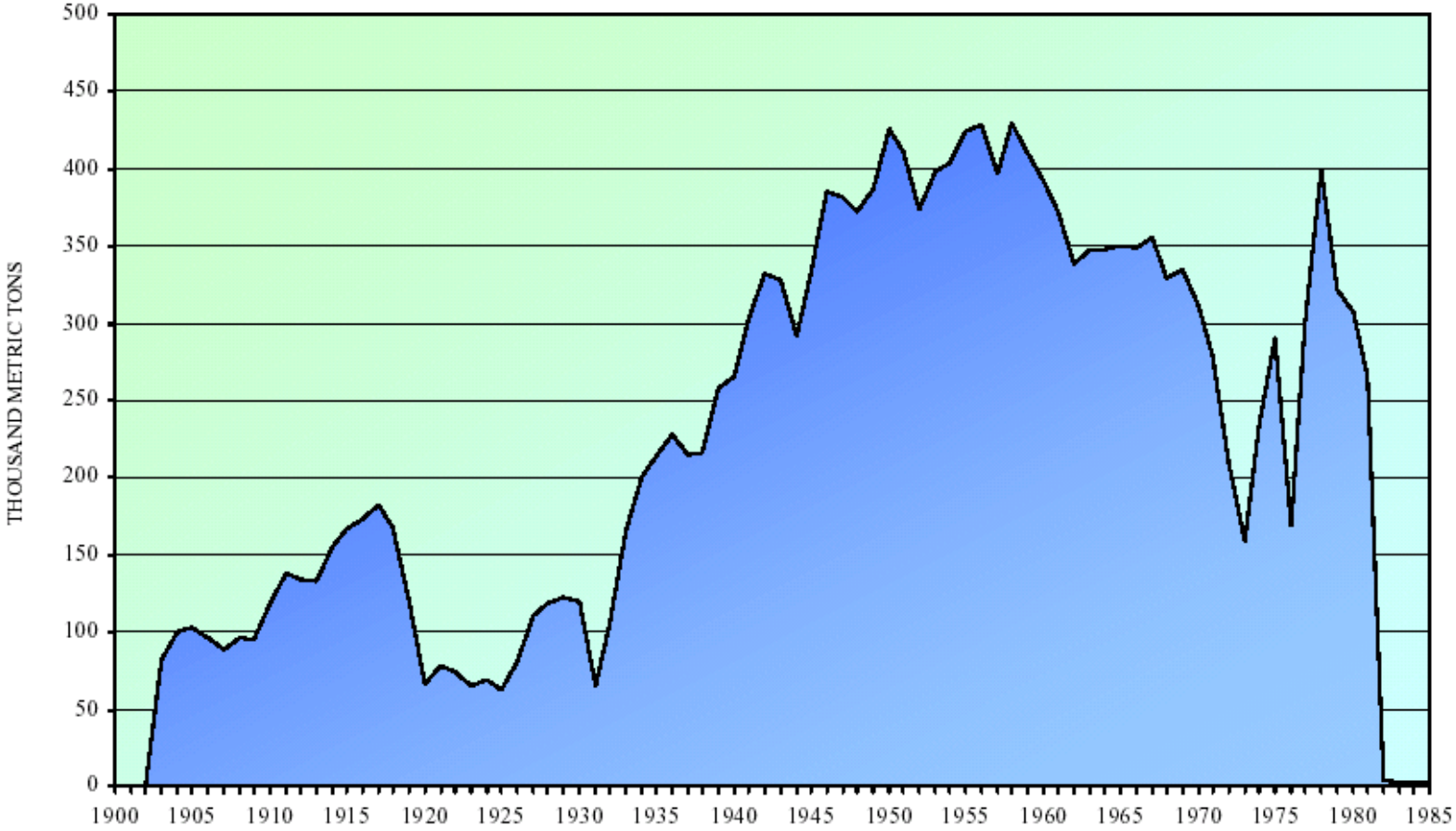

Figure 14. Chart that shows the production of pyrites in the United States. Pyrites production varied greatly from year to year from the first reports of its production until 1982 when its production became insignificant.

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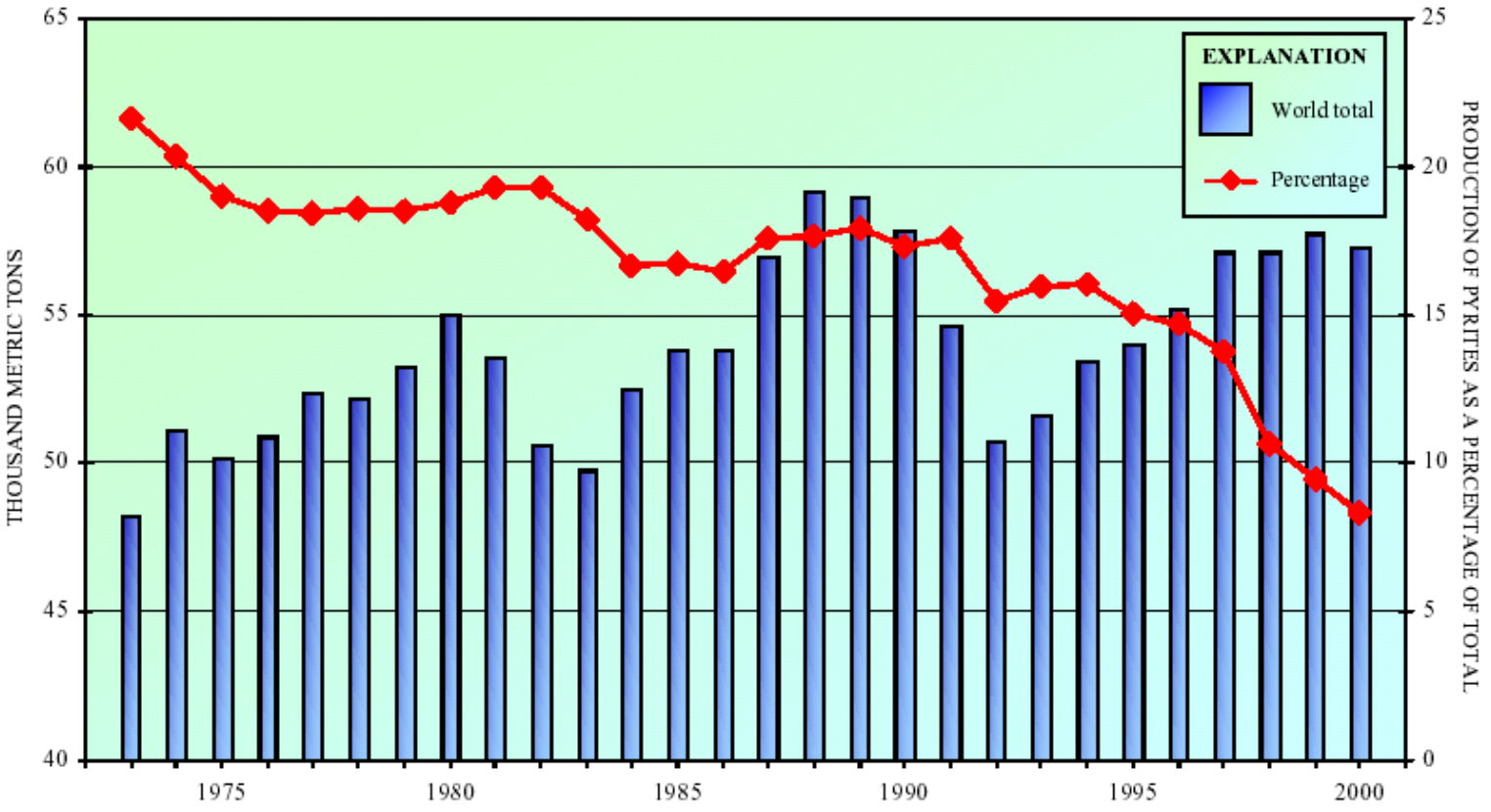

Figure 15. Chart that shows the relative importance of pyrites as a source of world sulfur production. Over time, the importance of pyrites as a sulfur source has decreased worldwide. In 1973, pyrites accounted for about 22% of world sulfur production; that figure dropped to less than 10% in 2000.

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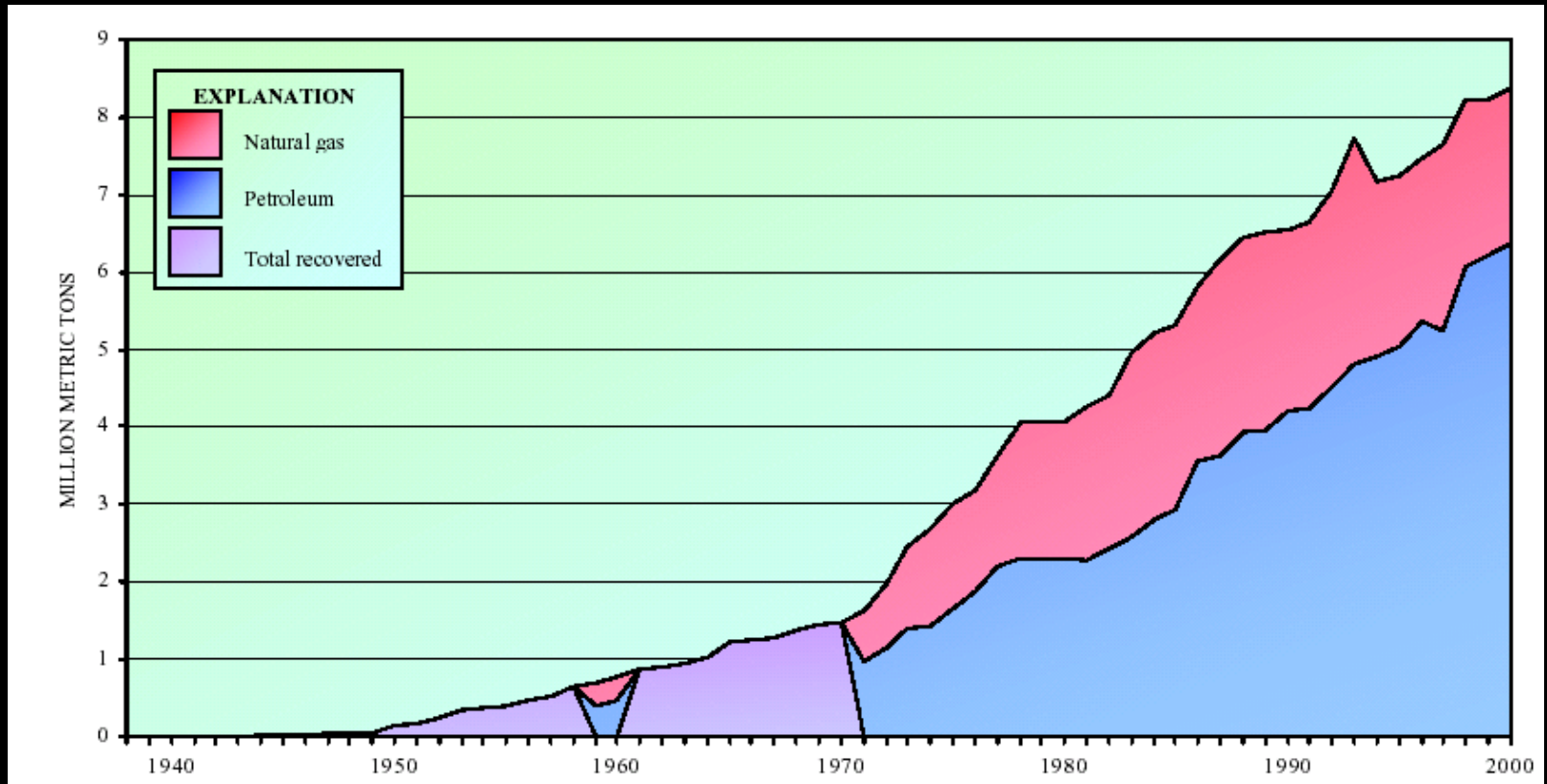

Figure 8. Chart that shows the steady growth in recovered sulfur from petroleum refineries and natural gas since 1938. The sources of recovered sulfur were identified in 1959 and 1960 and from 1971 to the present.

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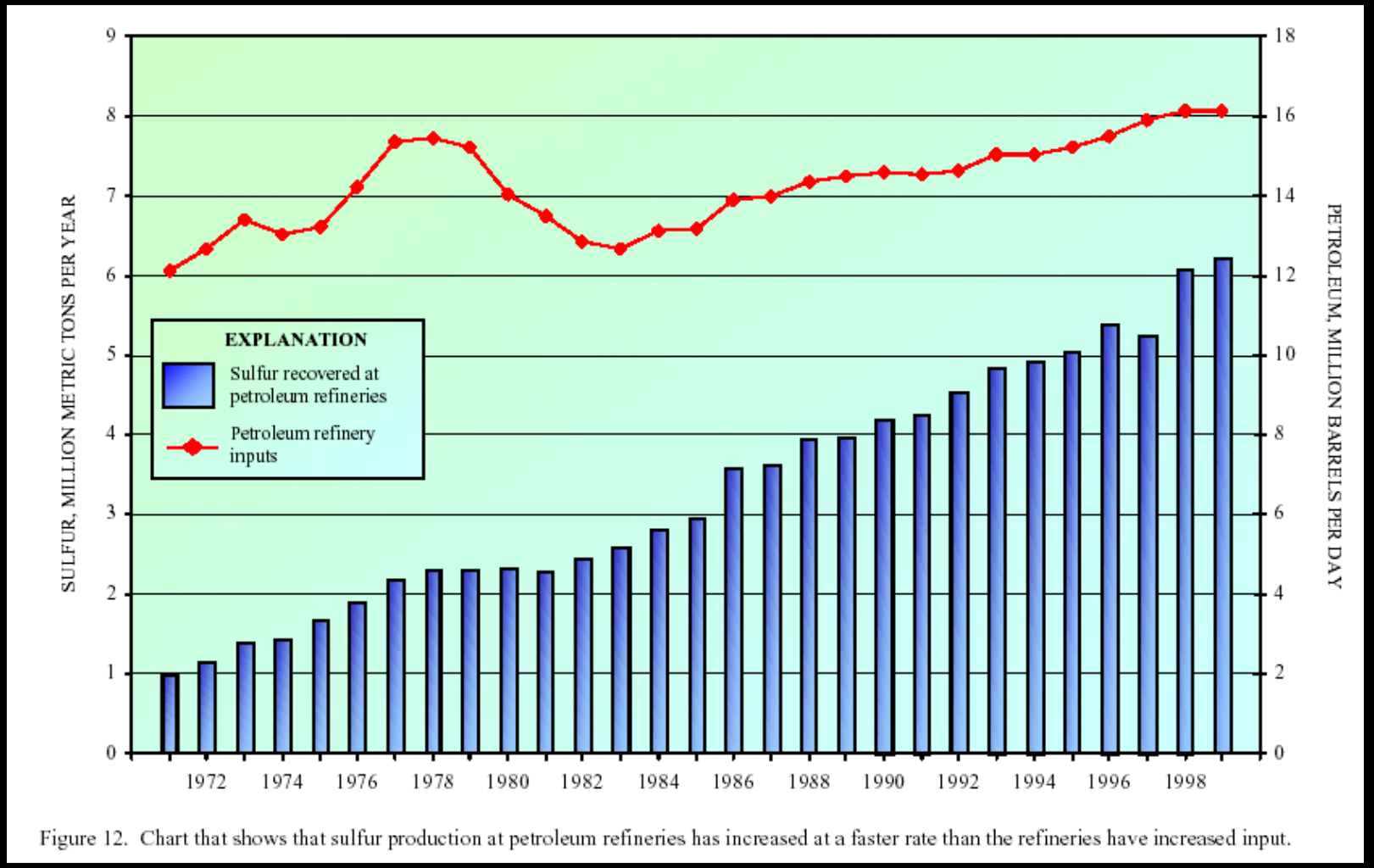

Figure 12. Chart that shows that sulfur production at petroleum refineries has increased at a faster rate than the refineries have increased input.

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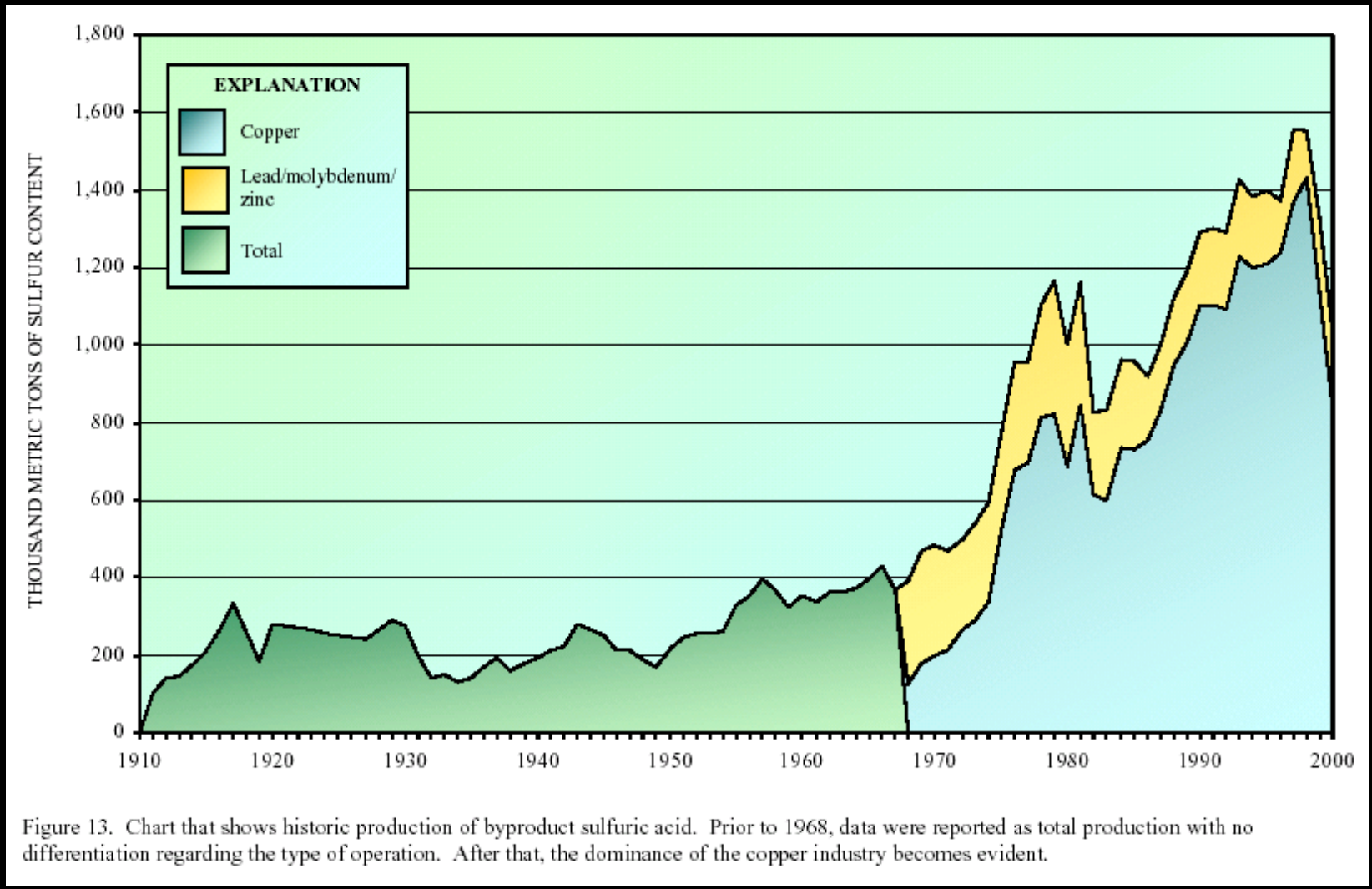

Figure 13. Chart that shows historic production of byproduct sulfuric acid. Prior to 1968, data were reported as total production with no differentiation regarding the type of operation. After that, the dominance of the copper industry becomes evident.

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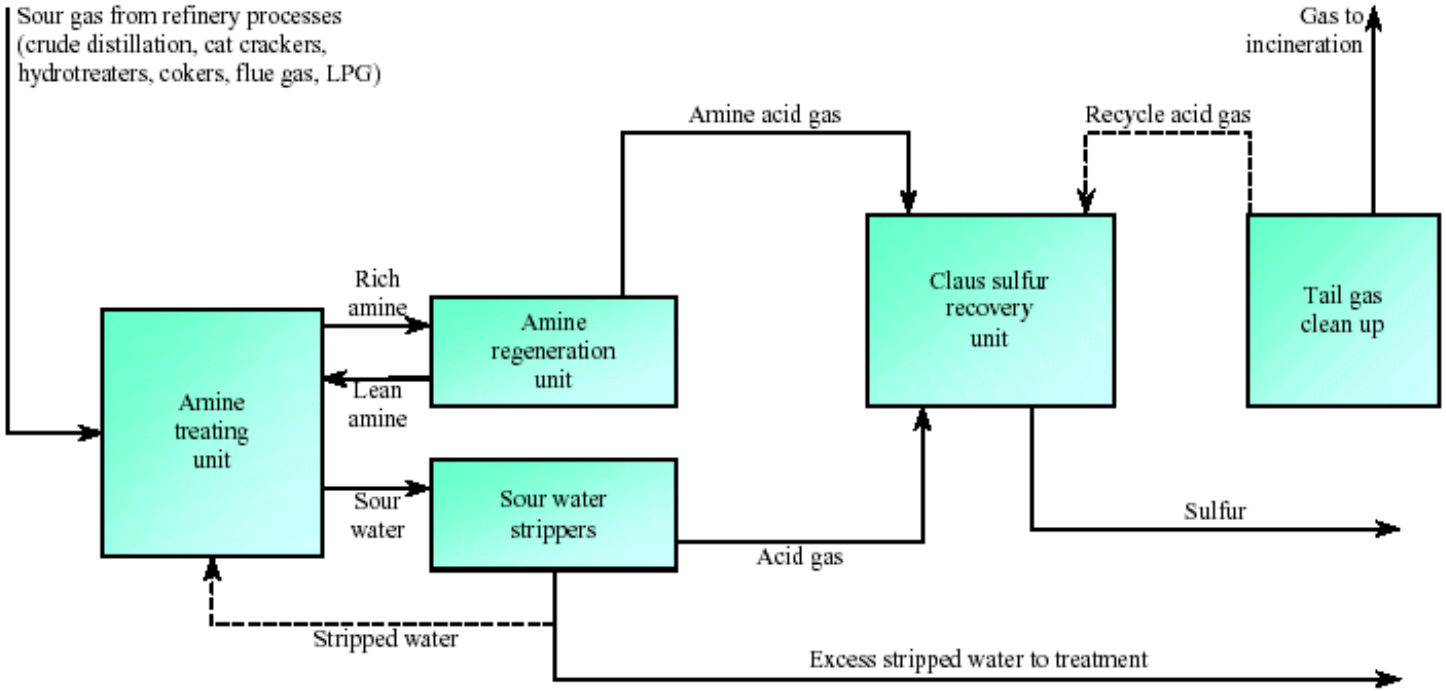

Figure 10. Flow diagram that shows the basic steps used in most sulfur recovery operations. Sour gas, which is gas that contains hydrogen sulfide (H_2S), is handled similarly at natural gas processing facilities and petroleum refineries.

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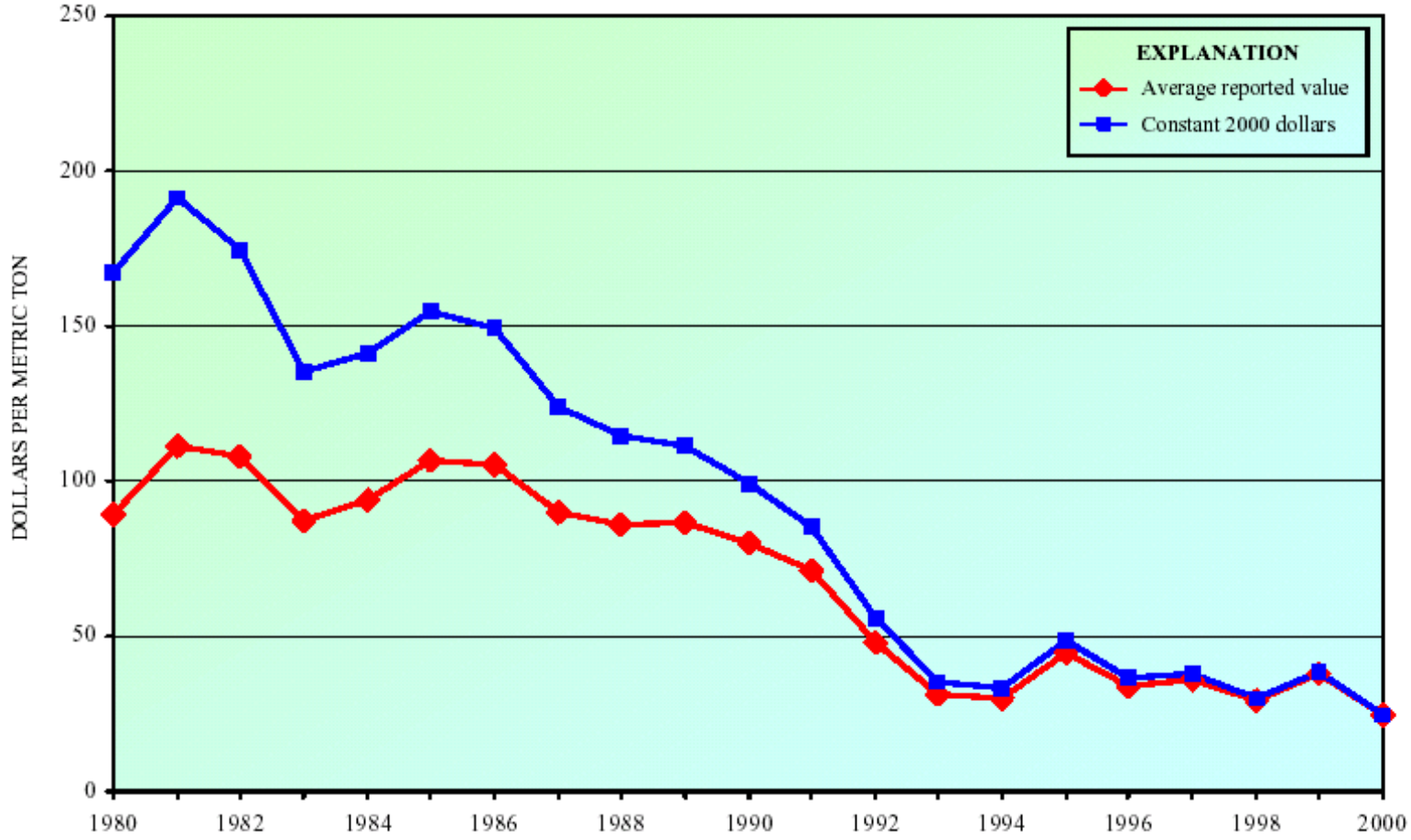

Figure 33. Chart that shows the prices of sulfur in the United States from 1980 through 2000. Sulfur prices generally have been in decline in the United States for the past 20 years. The data represented are the average value per metric ton of elemental sulfur as reported by domestic producers and those values translated to constant 2000 dollars.

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TABLE 2
RECOVERED SULFUR PRODUCED AND SHIPPED IN THE UNITED STATES, BY STATE 1/

(Thousand metric tons and thousand dollars)

State	2000			2001		
		Shipments			Shipments	
	Production	Quantity	Value	Production	Quantity	Value e/
Alabama	320	321	7,970	304	301	2,240
California	1,150	1,140	5,660	963	951	2,280
Illinois	444	444	5,900	436	437	837
Louisiana	1,070	2,180 2/	W	1,100	1,100	12,800
Michigan and Minnesota	34	34	483	35	36	176
Mississippi	525	533	20,100	559	551	22,200
New Mexico	48	48	(3/)	49	49	(3/)
North Dakota	50	50	(3/)	56	56	(3/)
Ohio	112	111	2,210	112	113	554
Texas	2,760	2,770	80,300 2/	2,740	2,740	36,700
Washington	113	110	27	102	102	(3/)
Wyoming	1,030	1,030	16,900	1,110	1,120	6,590
Other 4/	717	730	99,800	699	694	(1,480)
Total	8,380	9,500	239,000	8,270	8,250	82,900

See footnotes at end of table.

Pumice and pumicite

Pumice and pumicite—introduction

- Light colored, frothy volcanic rock
- Lava that is full of gas
- Floats on water

Pumice—uses

- Building blocks, 67%
- Abrasives, concrete, horticulture, landscaping, stone-washing laundries, and other applications, 33%

Pumice—production

Salient Statistics—United States:	2013	2014	2015	2016	2017[e]
Production, mine[1]	269	269	310	374	380
Imports for consumption	73	60	64	170	150
Exports[e]	13	14	11	9	11
Consumption, apparent[2]	329	315	363	535	520
Price, average value, dollars per ton, f.o.b. mine or mill	35	39	33	38	40
Employment, mine and mill, number	140	140	140	140	140
Net import reliance[3] as a percentage of apparent consumption	18	15	15	30	27

Recycling: Little to no known recycling.

thousand metric tons

Oregon, California, Idaho, New Mexico, and Kansas

Pumice—production

World Mine Production and Reserves:

	Mine production		Reserves[4]
	2016	2017[e]	
United States[1]	374	380	Large in the United States. Quantitative estimates of reserves for most countries are not available.
Algeria[5]	350	350	
Cameroon[5]	360	360	
Chile[5]	800	800	
Ecuador[5]	180	180	
Ethiopia	600	600	
France[5]	280	280	
Greece[5]	870	870	
Guadeloupe	200	200	
Italy[5]	4,000	4,000	
Saudi Arabia[5]	480	480	
Spain	200	200	
Syria[5]	260	260	
Turkey	6,700	6,700	
Uganda	740	740	
Other countries[5]	710	710	
World total (rounded)	17,100	17,000	

thousand metric tons

Pumice—geology

- Volcanic fields

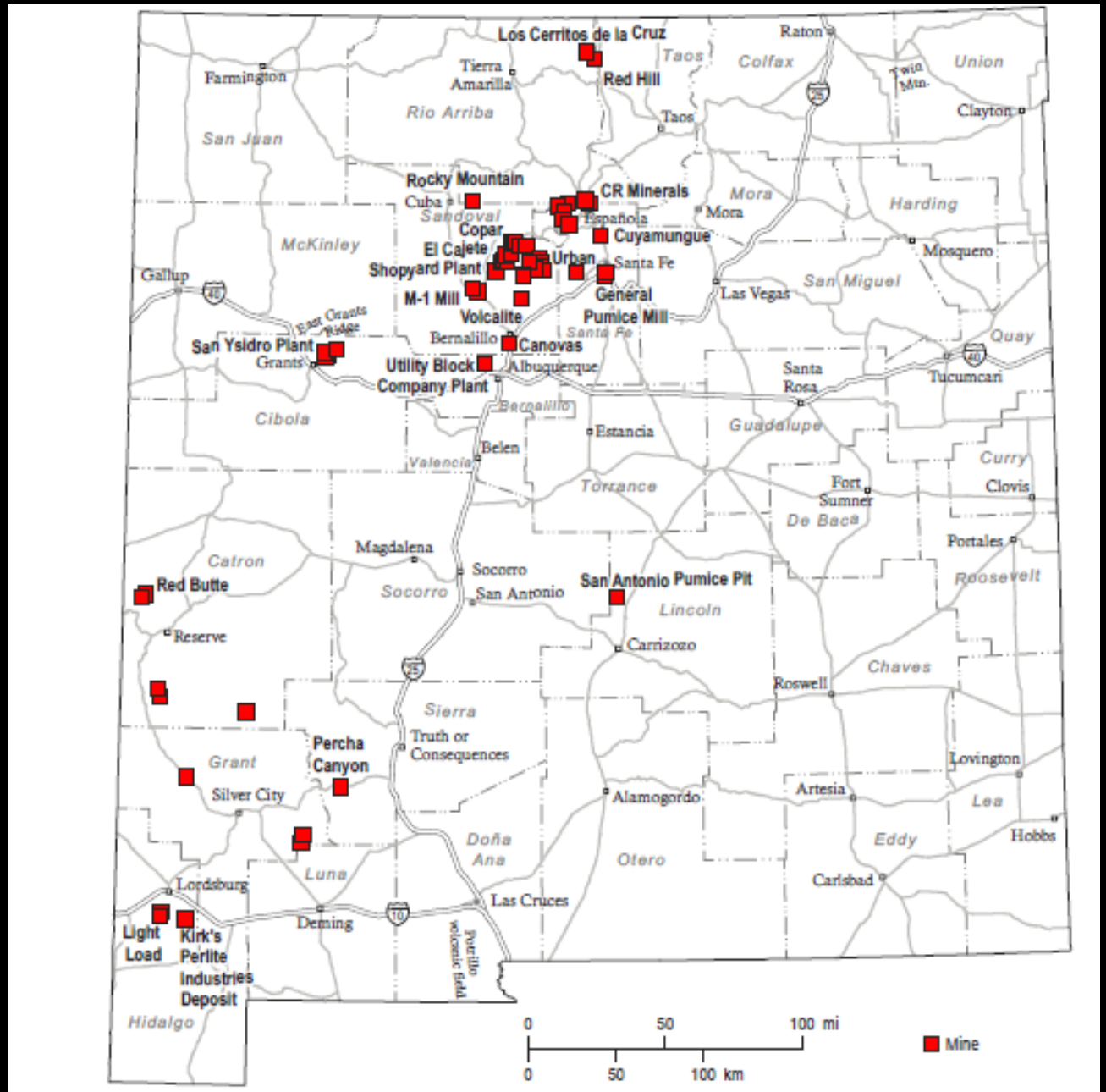

Figure 31. Index map showing the major pumiceous deposits and occurrences in New Mexico (modified from Hoffer, 1994).

Las Conchas pumice quarry, Sandoval County

Photograph by W.E. Scott on 27 June 1991

Dacitic pumice fragments erupted by Mount Pinatubo, Philippines, during an enormous eruption on 15 June 1991.

http://volcanoes.usgs.gov/Products/Pglossary/pumice.html

http://www.mineralminers.com/images/pumice/mins/pumm101.jpg

Photograph by J. Lowenstern in September 1990

Scoria exposed in the cross section of a cinder or scoria cone.

http://volcanoes.usgs.gov/Products/Pglossary/scoria.html

Reminders

- April 13 NMGS Spring Meeting
- April 14 Field trip
- April 28 AIPG meeting and Field trip in afternoon (perlite mine or carbonatites)
- Commodity presentation in April
- Research Projects presentations April 30
- Finals, Project written report due May 4
- No class May 7