Tracking Resources and Estimating Future Supplies

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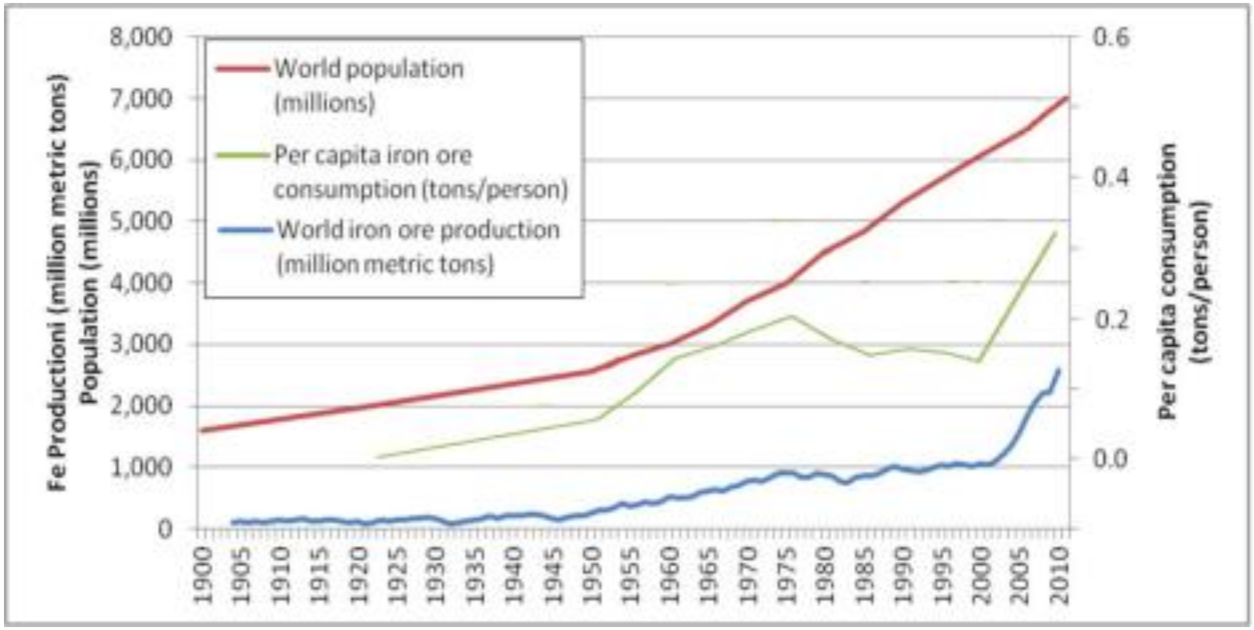
Oct. 29, 2013 Pardee P12: Resourcing Future Generations

Mineral Resources – The Big Picture

Global Trends in Population, Iron Ore Production, & Consumption, 1990-2011



Production data from USGS

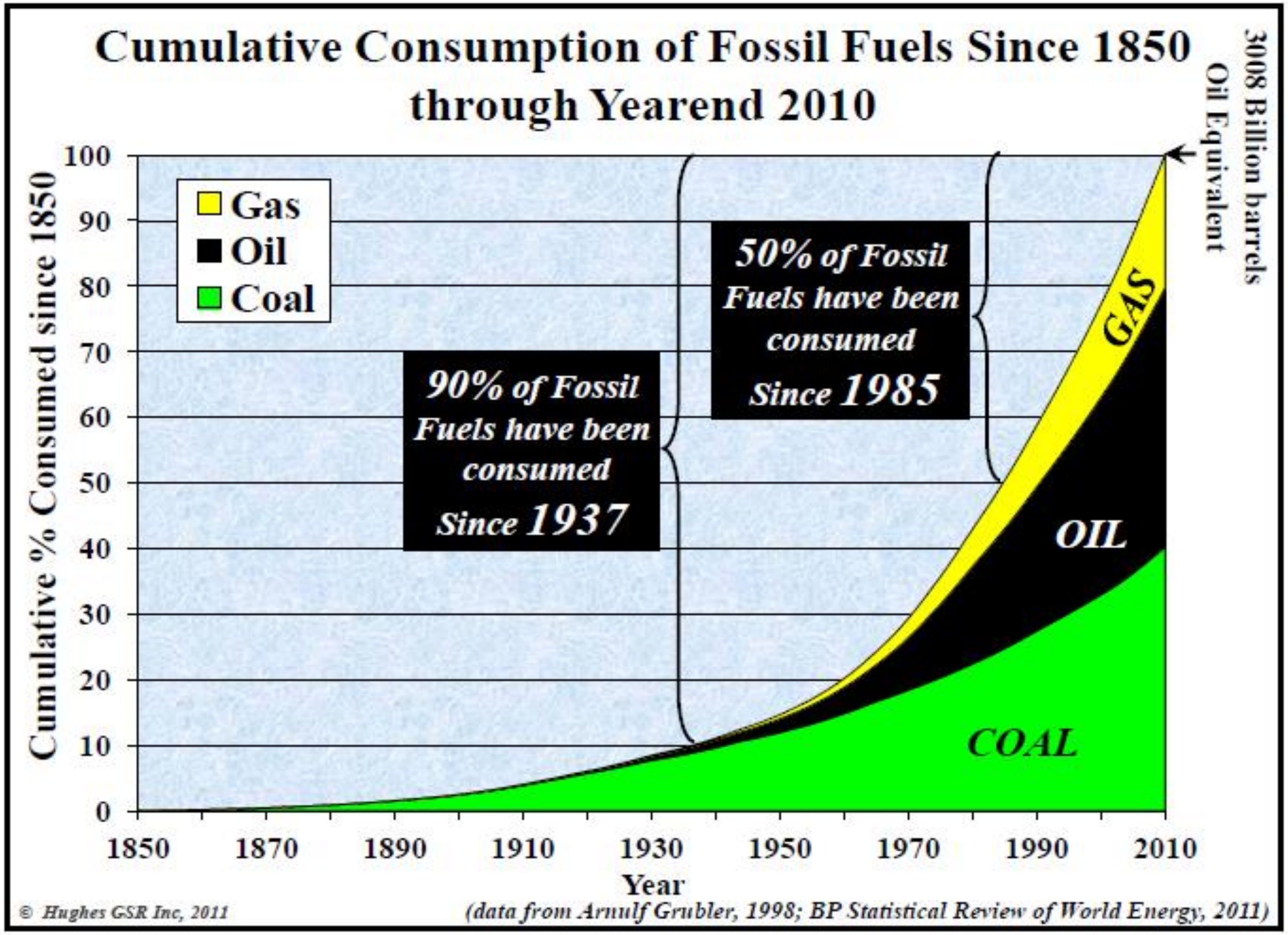
~4X more population than 100 years ago

~6X more per capita iron consumption than 100 years ago

~26X more iron ore production than 100 years ago

USGS

Fossil Fuels – a similar picture to mineral resources



J. David Hughes, 2012
(http://www.eeb.cornell.edu/howarth/HUGHES%20Cornell%20Ithaca%20May%202%202012.pdf)

USGS

World Trade

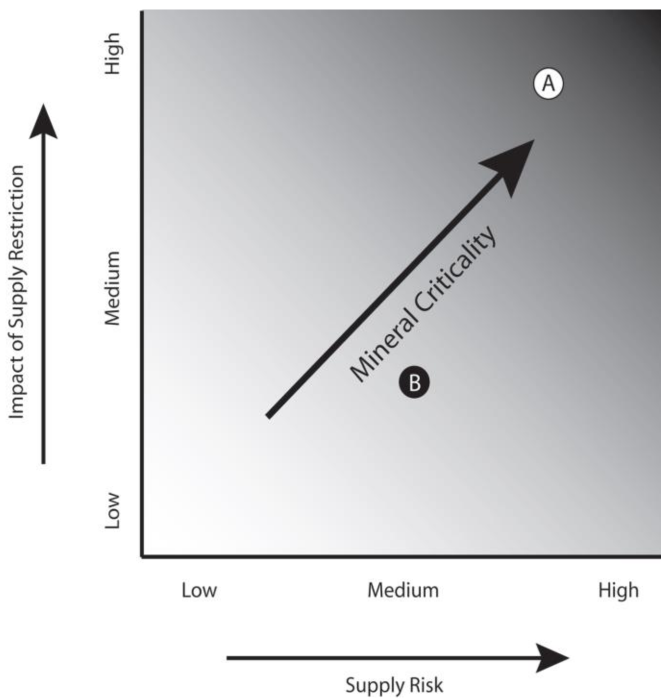
Although the US is a major producer and exporter of many commodities such as molybdenum and beryllium, it relies on world trade for most mineral resources and is >90% reliant on imports for 24 commodities, including REE

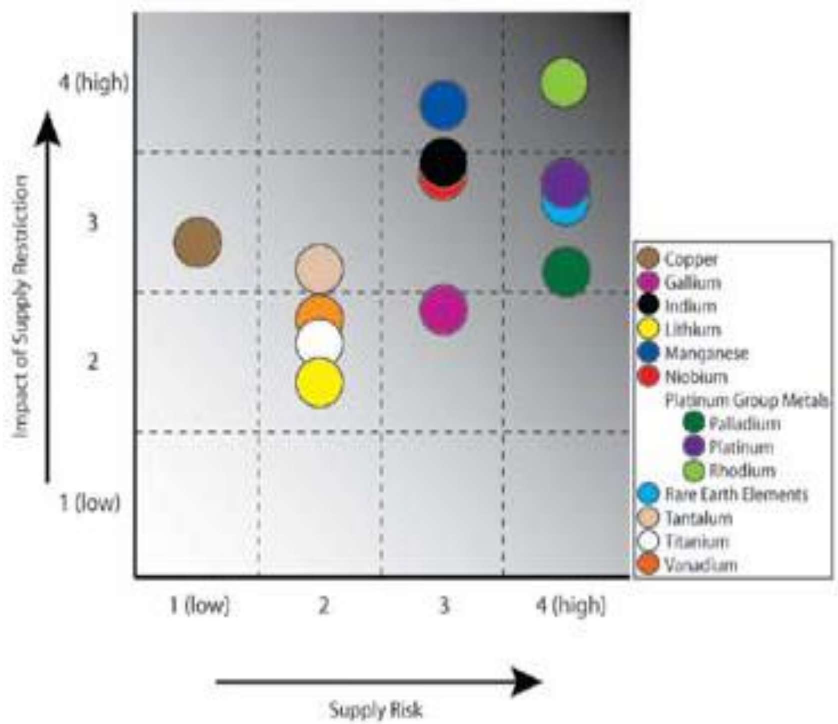
Source: USGS Mineral Commodity Summaries (2013)

2012 U.S. NET IMPORT RELIANCE[1]

Commodity	Percent	Major Import Sources (2008–11)[2]
ARSENIC (trioxide)	100	Morocco, China, Belgium
ASBESTOS	100	Canada, Zimbabwe
BAUXITE and ALUMINA	100	Jamaica, Brazil, Guinea, Australia
CESIUM	100	Canada
FLUORSPAR	100	Mexico, China, South Africa
GRAPHITE (natural)	100	China, Mexico, Canada, Brazil
INDIUM	100	China, Canada, Japan, Belgium
MANGANESE	100	South Africa, Gabon, Australia, China
MICA, sheet (natural)	100	China, Brazil, Belgium, India
NIOBIUM (columbium)	100	Brazil, Canada, Germany
QUARTZ CRYSTAL (industrial)	100	China, Japan, Russia
RUBIDIUM	100	Canada
SCANDIUM	100	China
STRONTIUM	100	Mexico, Germany, China
TANTALUM	100	China, Estonia, Germany, Kazakhstan
THALLIUM	100	Germany, Russia
THORIUM	100	India, France
GALLIUM	99	Germany, United Kingdom, China, Canada
GEMSTONES	99	Israel, India, Belgium, South Africa
VANADIUM	96	Rep. of Korea, Canada, Austria, Czech Republic
BISMUTH	92	China, Belgium, United Kingdom
PLATINUM	91	Germany, South Africa, United Kingdom, Canada
GERMANIUM	90	China, Belgium, Russia, Germany
IODINE	88	Chile, Japan
ANTIMONY	87	China, Mexico, Belgium, Bolivia
DIAMOND (dust, grit, and powder)	85	China, Ireland, Republic of Korea, Russia
STONE (dimension)	85	China, Brazil, Italy, Turkey
POTASH	81	Canada, Russia
BARITE	80	China, India, Morocco
COBALT	78	China, Norway, Russia, Finland
RHENIUM	78	Chile, Netherlands, Germany
TITANIUM MINERAL CONCENTRATES	77	South Africa, Australia, Canada, Mozambique
TIN	75	Peru, Bolivia, Indonesia, China
SILICON CARBIDE (crude)	73	China, South Africa, Romania, Netherlands
ZINC	72	Canada, Mexico, Peru, Spain
CHROMIUM	70	South Africa, Kazakhstan, Russia, Mexico
GARNET (industrial)	65	India, Australia, China, Canada
TITANIUM (sponge)	64	Japan, Kazakhstan, China, Ukraine,
PEAT	62	Canada
SILVER	57	Mexico, Canada, Peru, Poland
PALLADIUM	54	Russia, South Africa, United Kingdom, Norway
NICKEL	49	Canada, Russia, Australia, Norway
MAGNESIUM COMPOUNDS	46	China, Canada, Brazil, Australia
TUNGSTEN	42	China, Bolivia, Canada, Germany
SILICON	36	Brazil, Russia, China, Canada
COPPER	35	Chile, Canada, Peru, Mexico
NITROGEN (fixed), AMMONIA	35	Trinidad and Tobago, Russia, Canada, Ukraine
MAGNESIUM METAL	31	Israel, Canada, China
MICA, scrap and flake (natural)	31	Canada, China, India, Finland
VERMICULITE	30	South Africa, China, Brazil, Australia
PERLITE	24	Greece
ALUMINUM	20	Canada, Russia, China, Mexico
SALT	19	Canada, Chile, Mexico, The Bahamas
SULFUR	19	Canada, Mexico, Venezuela
PUMICE	15	Greece, Iceland, Mexico, Montserrat
GYPSUM	12	Canada, Mexico, Spain

A critical mineral as defined in a 2008 National Academy of Sciences report is one that is both essential in use and subject to the risk of supply restriction

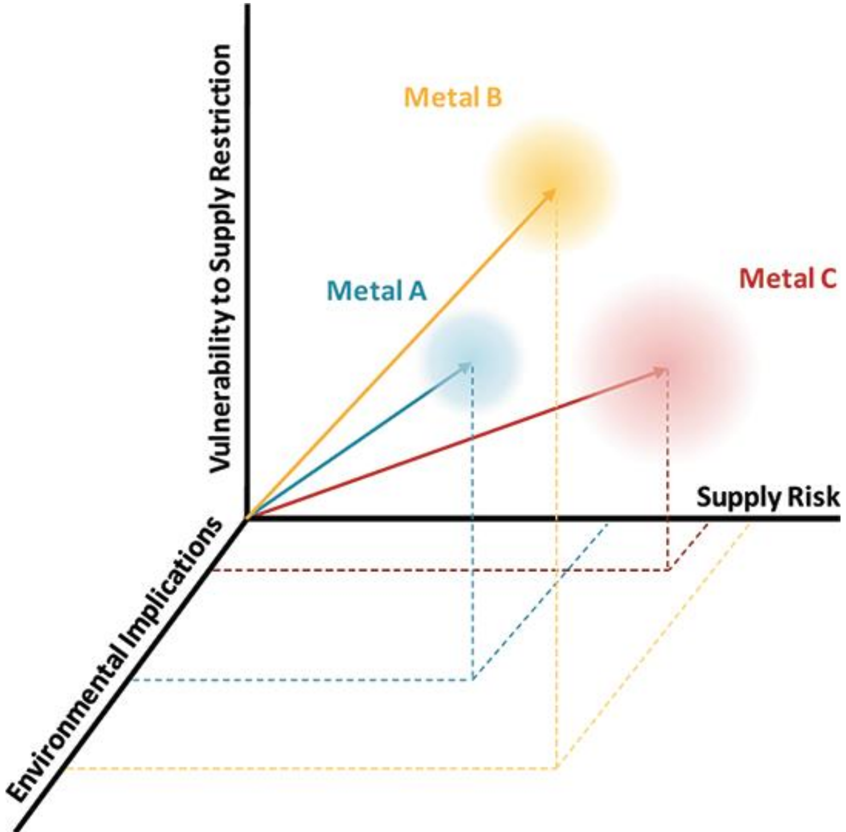




Criticality is context specific:

- What is critical for a given manufacturer or product may not be critical for another, what is critical for a state may not be critical for a country, and what is critical for national defense may be different than what is necessary to make a television brighter or less expensive.

- Recent studies have expanded the scope of criticality to include environmental and technological factors.



Graedel, T. E.; Barr, R.; Chandler, C.; Chase, T.; Choi, J.; Christoffersen, L.; Friedlander, E.; Henly, C.; Nassar, N. T.;Schechner, D.; Warren, S.; Yang, M.; Zhu, C., 2012, Methodology of metal criticality determination: Environ. Sci. Technol., 46, 1063−1070.

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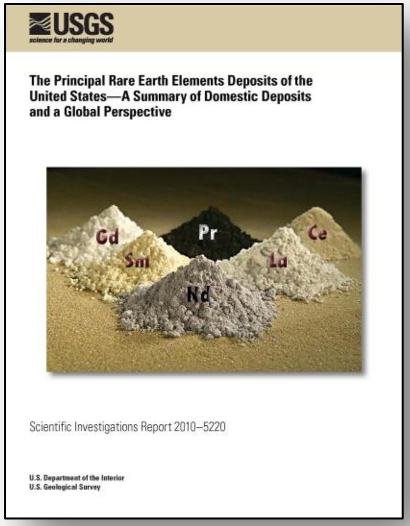
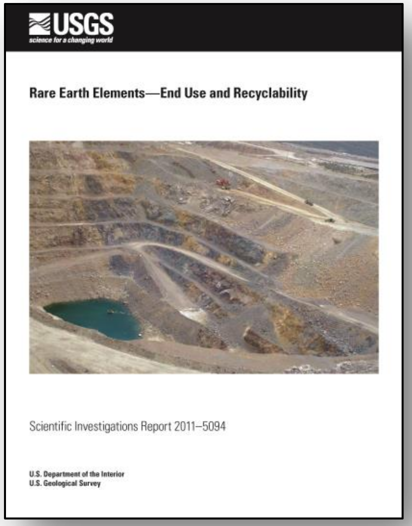
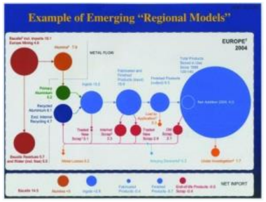
Information is Critical





The Global Flow of Aluminum From 2006 Through 2025: *USGS Open-file Report 2010-1256*



Mines and Mineral Processing Facilities in the Vicinity of the March 11, 2011, Earthquake in Northern Honshu: *USGS Open-file Report 2011-1069*

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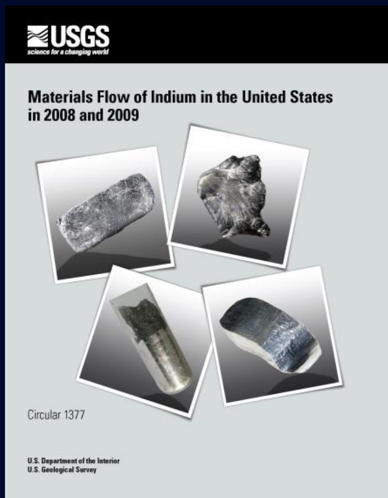
Minerals Information

Materials Flow Studies


USGS science for a changing world

Materials Flow of Indium in the United States in 2008 and 2009

Circular 1377

U.S. Department of the Interior
U.S. Geological Survey

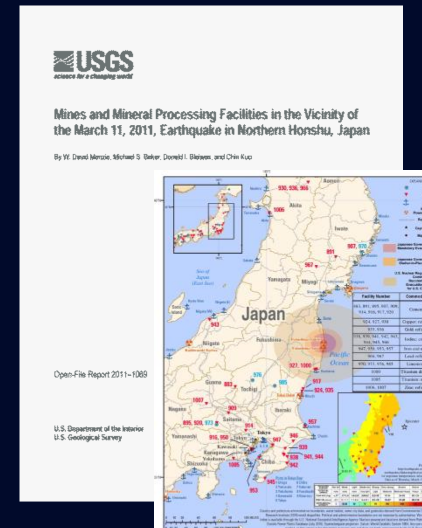

USGS science for a changing world

Byproduct Metals and Rare-Earth Elements Used in the Production of Light-Emitting Diodes—Overview of Principal Sources of Supply and Material Requirements for Selected Markets

Byproduct raw materials
Manufactured components
Light-emitting diode assembly

Scientific Investigation:

U.S. Department of the Interior
U.S. Geological Survey


USGS science for a changing world

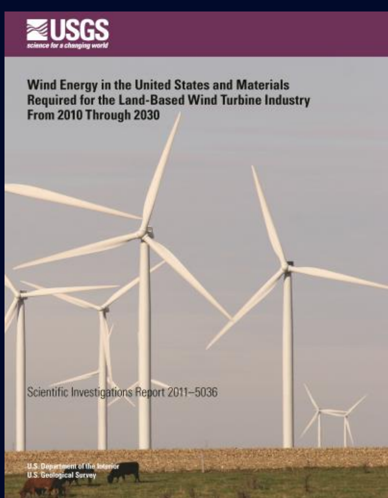
Mines and Mineral Processing Facilities in the Vicinity of the March 11, 2011, Earthquake in Northern Honshu, Japan

By W. David Menzie, Michael S. Baker, Donald I. Bleiwas, and Chin Kuo

Japan

Open-File Report 2011–1089

U.S. Department of the Interior
U.S. Geological Survey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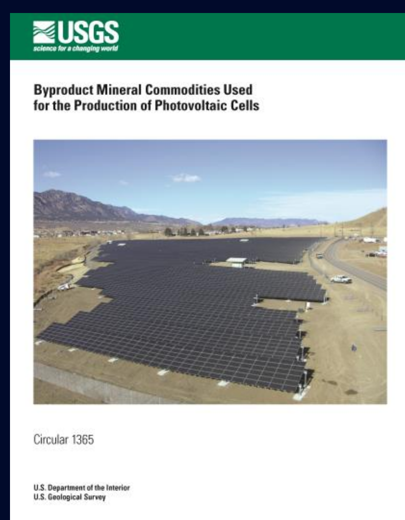
Wind Energy in the United States and Materials Required for the Land-Based Wind Turbine Industry From 2010 Through 2030

Scientific Investigations Report 2011–5036

U.S. Department of the Interior
U.S. Geological Survey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Byproduct Mineral Commodities Used for the Production of Photovoltaic Cells

Circular 1365

U.S. Department of the Interior
U.S. Geological Survey


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Lithium Use in Batteries

Circular 1371

U.S. Department of the Interior
U.S. Geological Survey


USGS science for a changing world

Recent Strikes in South Africa's Platinum-Group Metal Mines: Effects Upon World Platinum-Group Metal Supplies

By Thomas R. Yager, Yadira Soto-Viruet, and James J. Barry

Open-File Report 2012–1273

U.S. Department of the Interior
U.S. Geological Survey

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Supply Disruption

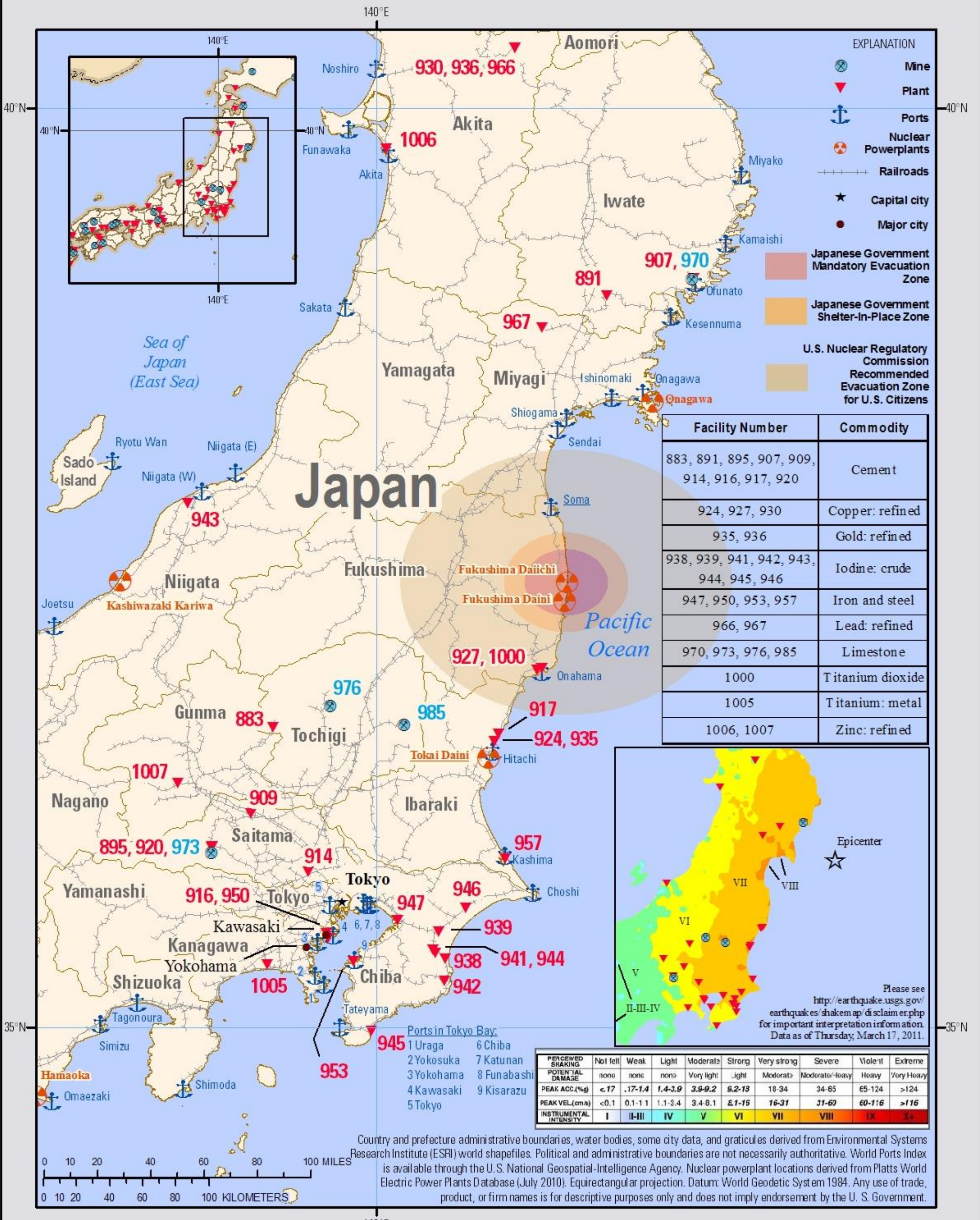
Facilities in impact zone of March 11, 2011, magnitude 9.0 earthquake and associated tsunami :

9 cement plants
4 iron and steel plants
3 copper refineries
2 lead refineries
1 titanium dioxide plant
1 titanium sponge processing facility.
8 iodine plants
4 limestone mines
2 gold refineries
2 zinc refineries

These facilities have the capacity to produce the following percentages of the world's nonfuel mineral production:

25 % of iodine (Japan is world's second leading producer (after Chile))
10 % of titanium sponge (metal)
3 % of refined zinc
2.5 % of refined copper
1.4 % of steel

The 9 cement plants produce 30% of Japan's annual cement production



Facility Number	Commodity
883, 891, 895, 907, 909, 914, 916, 917, 920	Cement
924, 927, 930	Copper: refined
935, 936	Gold: refined
938, 939, 941, 942, 943, 944, 945, 946	Iodine: crude
947, 950, 953, 957	Iron and steel
966, 967	Lead: refined
970, 973, 976, 985	Limestone
1000	Titanium dioxide
1005	Titanium: metal
1006, 1007	Zinc: refined

Figure 1.—Map showing the location of mines and mineral facilities in Japan. Modified from Baker and others (2010).

2

Menzie, W.D., Baker, M.S., Bleiwas, D.I., and Kuo, Chin, 2011, Mines and mineral processing facilities in the vicinity of the March 11, 2011, earthquake in northern Honshu, Japan: U.S. Geological Survey Open-File Report 2011–1069, 7 p. (Available only at http://pubs.usgs.gov/of/2011/1069/.)

USGS

Periodic Table of the Elements

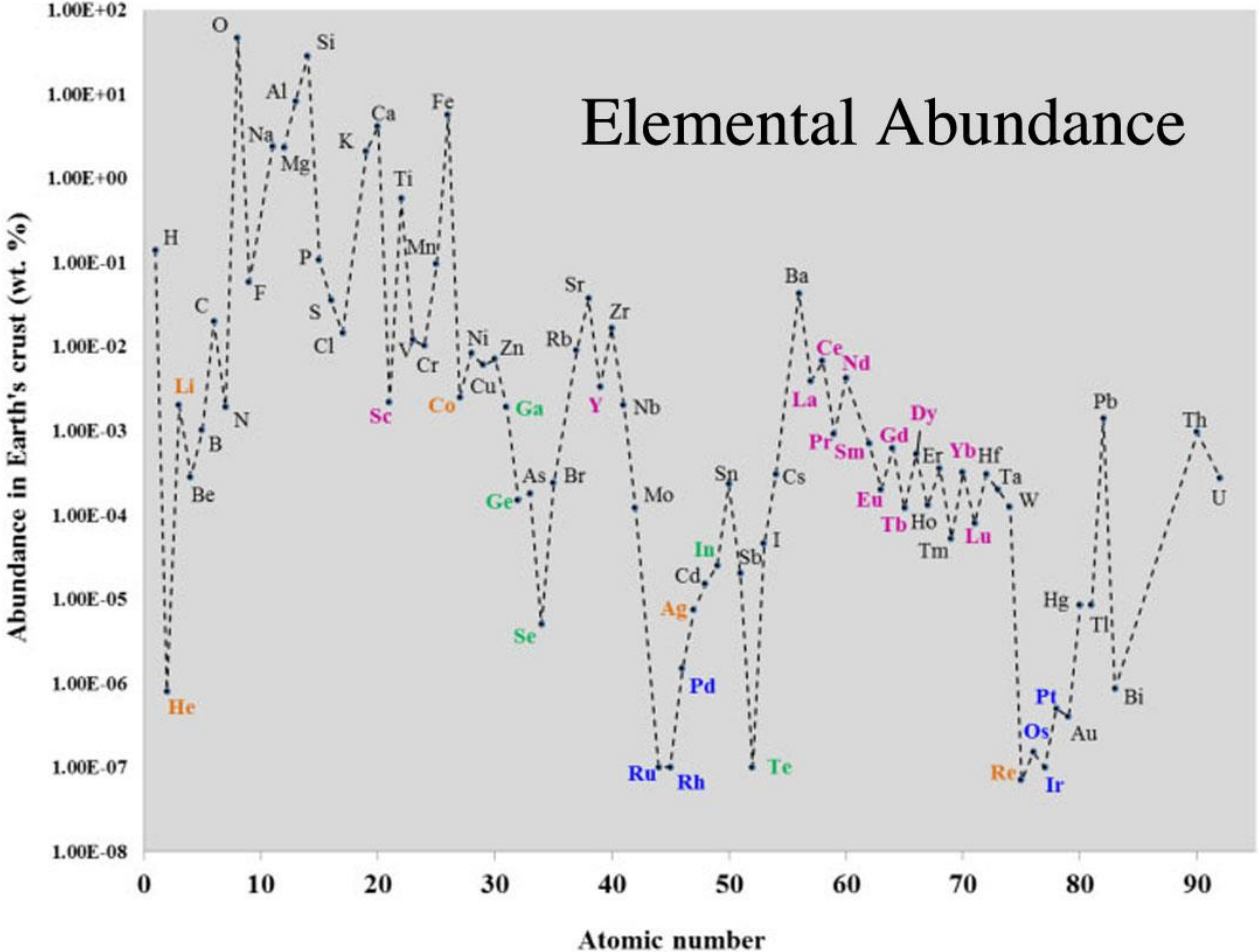
1A	2A	3B	4B	5B	6B	7B	8B	8B	8B	11B	12B	3A	4A	5A	6A	7A	8A
1 H $1s^1$ hydrogen 1.008																	2 He $1s^2$ helium 4.003
3 Li [He]$2s^1$ lithium 6.941	4 Be [He]$2s^2$ beryllium 9.012											5 B [He]$2s^22p^1$ boron 10.81	6 C [He]$2s^22p^2$ carbon 12.01	7 N [He]$2s^22p^3$ nitrogen 14.01	8 O [He]$2s^22p^4$ oxygen 16.00	9 F [He]$2s^22p^5$ fluorine 19.00	10 Ne [He]$2s^22p^6$ neon 20.18
11 Na [Ne]$3s^1$ sodium 22.99	12 Mg [Ne]$3s^2$ magnesium 24.31											13 Al [Ne]$3s^23p^1$ aluminum 26.98	14 Si [Ne]$3s^23p^2$ silicon 28.09	15 P [Ne]$3s^23p^3$ phosphorus 30.97	16 S [Ne]$3s^23p^4$ sulfur 32.07	17 Cl [Ne]$3s^23p^5$ chlorine 35.45	18 Ar [Ne]$3s^23p^6$ argon 39.95
19 K [Ar]$4s^1$ potassium 39.10	20 Ca [Ar]$4s^2$ calcium 40.08	21 Sc [Ar]$4s^23d^1$ scandium 44.96	22 Ti [Ar]$4s^23d^2$ titanium 47.88	23 V [Ar]$4s^23d^3$ vanadium 50.94	24 Cr [Ar]$4s^13d^5$ chromium 52.00	25 Mn [Ar]$4s^23d^5$ manganese 54.94	26 Fe [Ar]$4s^23d^6$ iron 55.85	27 Co [Ar]$4s^23d^7$ cobalt 58.93	28 Ni [Ar]$4s^23d^8$ nickel 58.69	29 Cu [Ar]$4s^13d^{10}$ copper 63.55	30 Zn [Ar]$4s^23d^{10}$ zinc 65.39	31 Ga [Ar]$4s^23d^{10}4p^1$ gallium 69.72	32 Ge [Ar]$4s^23d^{10}4p^2$ germanium 72.64	33 As [Ar]$4s^23d^{10}4p^3$ arsenic 74.92	34 Se [Ar]$4s^23d^{10}4p^4$ selenium 78.96	35 Br [Ar]$4s^23d^{10}4p^5$ bromine 79.90	36 Kr [Ar]$4s^23d^{10}4p^6$ krypton 83.79
37 Rb [Kr]$5s^1$ rubidium 85.47	38 Sr [Kr]$5s^2$ strontium 87.62	39 Y [Kr]$5s^24d^1$ yttrium 88.91	40 Zr [Kr]$5s^24d^2$ zirconium 91.22	41 Nb [Kr]$5s^14d^4$ niobium 92.91	42 Mo [Kr]$5s^14d^5$ molybdenum 95.94	43 Tc [Kr]$5s^24d^5$ technetium (98)	44 Ru [Kr]$5s^14d^7$ ruthenium 101.1	45 Rh [Kr]$5s^14d^8$ rhodium 102.9	46 Pd [Kr]$4d^{10}$ palladium 106.4	47 Ag [Kr]$5s^14d^{10}$ silver 107.9	48 Cd [Kr]$5s^24d^{10}$ cadmium 112.4	49 In [Kr]$5s^24d^{10}5p^1$ indium 114.8	50 Sn [Kr]$5s^24d^{10}5p^2$ tin 118.7	51 Sb [Kr]$5s^24d^{10}5p^3$ antimony 121.8	52 Te [Kr]$5s^24d^{10}5p^4$ tellurium 127.6	53 I [Kr]$5s^24d^{10}5p^5$ iodine 126.9	54 Xe [Kr]$5s^24d^{10}5p^6$ xenon 131.3
55 Cs [Xe]$6s^1$ cesium 132.9	56 Ba [Xe]$6s^2$ barium 137.3	*	72 Hf [Xe]$6s^24f^{14}5d^2$ hafnium 178.5	73 Ta [Xe]$6s^24f^{14}5d^3$ tantalum 180.9	74 W [Xe]$6s^24f^{14}5d^4$ tungsten 183.9	75 Re [Xe]$6s^24f^{14}5d^5$ rhenium 186.2	76 Os [Xe]$6s^24f^{14}5d^6$ osmium 190.2	77 Ir [Xe]$6s^24f^{14}5d^7$ iridium 192.2	78 Pt [Xe]$6s^14f^{14}5d^9$ platinum 195.1	79 Au [Xe]$6s^14f^{14}5d^{10}$ gold 197.0	80 Hg [Xe]$6s^24f^{14}5d^{10}$ mercury 200.5	81 Tl [Xe]$6s^24f^{14}5d^{10}6p^1$ thallium 204.4	82 Pb [Xe]$6s^24f^{14}5d^{10}6p^2$ lead 207.2	83 Bi [Xe]$6s^24f^{14}5d^{10}6p^3$ bismuth 209.0	84 Po [Xe]$6s^24f^{14}5d^{10}6p^4$ polonium (209)	85 At [Xe]$6s^24f^{14}5d^{10}6p^5$ astatine (210)	86 Rn [Xe]$6s^24f^{14}5d^{10}6p^6$ radon (222)
87 Fr [Rn]$7s^1$ francium (223)	88 Ra [Rn]$7s^2$ radium (226)	**	104 Rf [Rn]$7s^25f^{14}6d^2$ rutherfordium (261)	105 Db [Rn]$7s^25f^{14}6d^3$ dubnium (262)	106 Sg [Rn]$7s^25f^{14}6d^4$ seaborgium (266)	107 Bh [Rn]$7s^25f^{14}6d^5$ bohrium (264)	108 Hs [Rn]$7s^25f^{14}6d^6$ hassium (277)	109 Mt [Rn]$7s^25f^{14}6d^7$ meitnerium (268)	110 Ds [Rn]$7s^15f^{14}6d^9$ darmstadtium (271)	111 Rg roentgenium (272)	112 Cn copernicium (277)	113 Uut (?)	114 Uuq (285)	115 Uup (?)	116 Uuh (289)	117 Uus (?)	118 Uuo (?)

Lanthanide Series*	57 La [Xe]$6s^25d^1$ lanthanum 138.9	58 Ce [Xe]$6s^24f^15d^1$ cerium 140.1	59 Pr [Xe]$6s^24f^3$ praseodymium 140.9	60 Nd [Xe]$6s^24f^4$ neodymium 144.2	61 Pm [Xe]$6s^24f^5$ promethium (145)	62 Sm [Xe]$6s^24f^6$ samarium 150.4	63 Eu [Xe]$6s^24f^7$ europium 152.0	64 Gd [Xe]$6s^24f^75d^1$ gadolinium 157.2	65 Tb [Xe]$6s^24f^9$ terbium 158.9	66 Dy [Xe]$6s^24f^{10}$ dysprosium 162.5	67 Ho [Xe]$6s^24f^{11}$ holmium 164.9	68 Er [Xe]$6s^24f^{12}$ erbium 167.3	69 Tm [Xe]$6s^24f^{13}$ thulium 168.9	70 Yb [Xe]$6s^24f^{14}$ ytterbium 173.0	71 Lu [Xe]$6s^24f^{14}5d^1$ lutetium 175.0
Actinide Series**	89 Ac [Rn]$7s^26d^1$ actinium (227)	90 Th [Rn]$7s^26d^2$ thorium 232.0	91 Pa [Rn]$7s^25f^26d^1$ protactinium 231	92 U [Rn]$7s^25f^36d^1$ uranium 238	93 Np [Rn]$7s^25f^46d^1$ neptunium (237)	94 Pu [Rn]$7s^25f^6$ plutonium (244)	95 Am [Rn]$7s^25f^7$ americium (243)	96 Cm [Rn]$7s^25f^76d^1$ curium (247)	97 Bk [Rn]$7s^25f^9$ berkelium (247)	98 Cf [Rn]$7s^25f^{10}$ californium (251)	99 Es [Rn]$7s^25f^{11}$ einsteinium (252)	100 Fm [Rn]$7s^25f^{12}$ fermium (257)	101 Md [Rn]$7s^25f^{13}$ mendelevium (258)	102 No [Rn]$7s^25f^{14}$ nobelium (259)	103 Lr [Rn]$7s^25f^{14}6d^1$ lawrencium (262)

element names in blue are liquids at room temperature
element names in red are gases at room temperature
element names in black are solids at room temperature

Los Alamos NATIONAL LABORATORY

Los Alamos National Laboratory Chemistry Division



Elemental Abundance
Abundance in Earth's crust (wt. %)
Atomic number
1.00E+02
1.00E+01
1.00E+00
1.00E-01
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E-06
1.00E-07
1.00E-08
0
10
20
30
40
50
60
70
80
90
H
He
Li
Be
B
C
N
O
F
Na
Mg
Al
Si
P
S
Cl
K
Ca
Sc
Ti
V
Cr
Mn
Fe
Co
Ni
Cu
Zn
Ga
Ge
As
Se
Br
Rb
Sr
Y
Zr
Nb
Mo
Ru
Rh
Pd
Ag
Cd
In
Sn
Sb
Te
I
Cs
Ba
La
Ce
Pr
Nd
Sm
Eu
Gd
Tb
Dy
Ho
Er
Tm
Yb
Lu
Hf
Ta
W
Re
Os
Ir
Pt
Au
Hg
Tl
Pb
Bi
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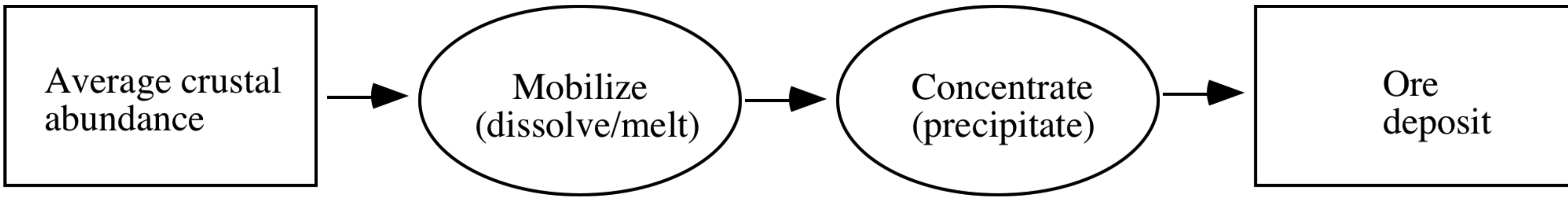
U

To geochemist ore deposits are simple chemical reactions



Distribution of element - primary affinities derived from empirical study of meteorites & slag 1) siderophile (Fe) 2) chalcophile (S) 3) lithophile (Si)

- secondary affinities follow Goldschmidt's rules of ionic size and charge

for example: Ni+2 (0.69) Fe+2 (0.74) Mg+2 (0.66) in olivine $(Mg,Fe)_2SiO_4$

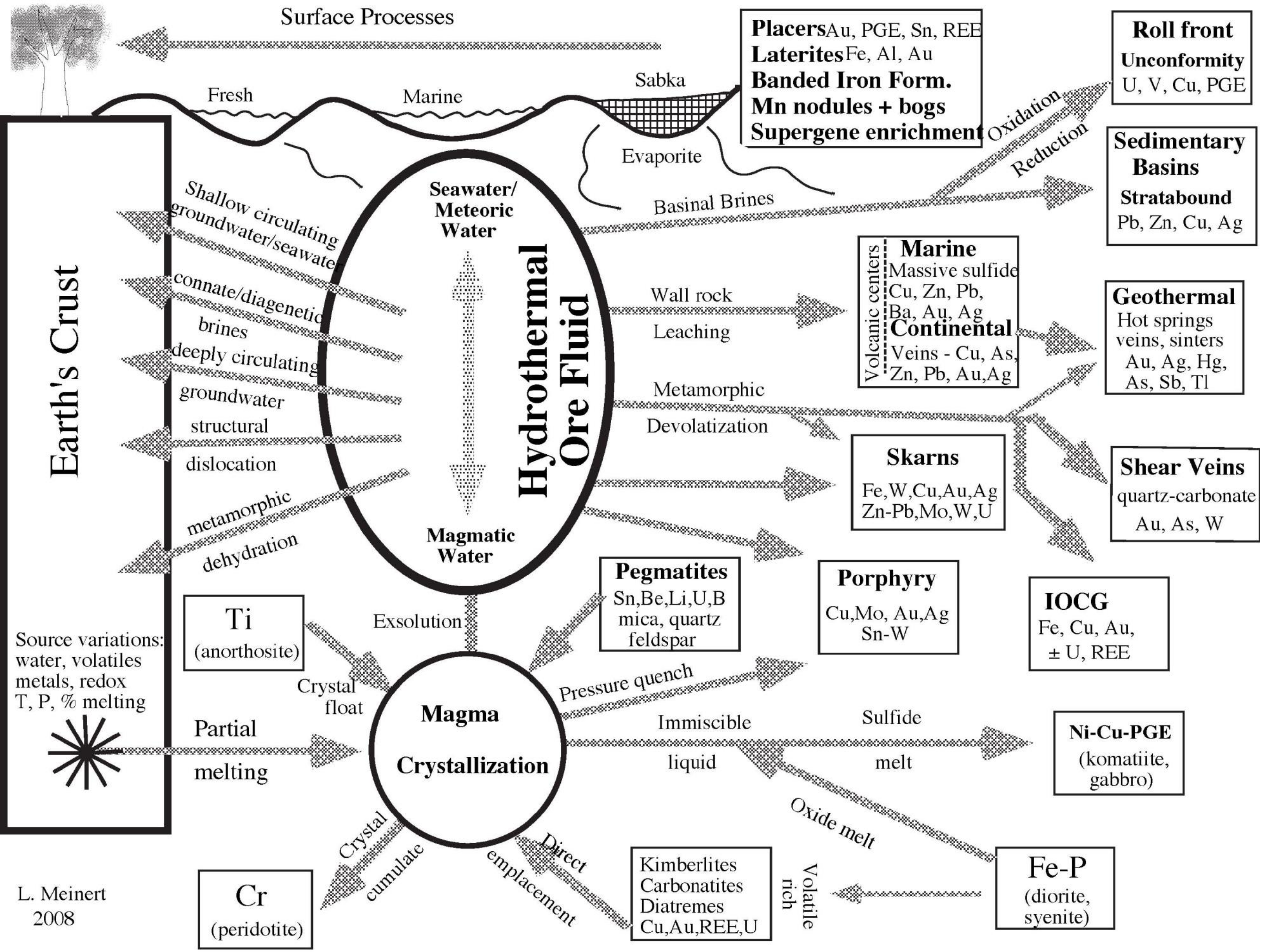
Abundance vs availability: Zr more abundant (.02) than Cu or Zn yet not available - <u>dispersed</u> as <u>refractory</u> zircon

USGS

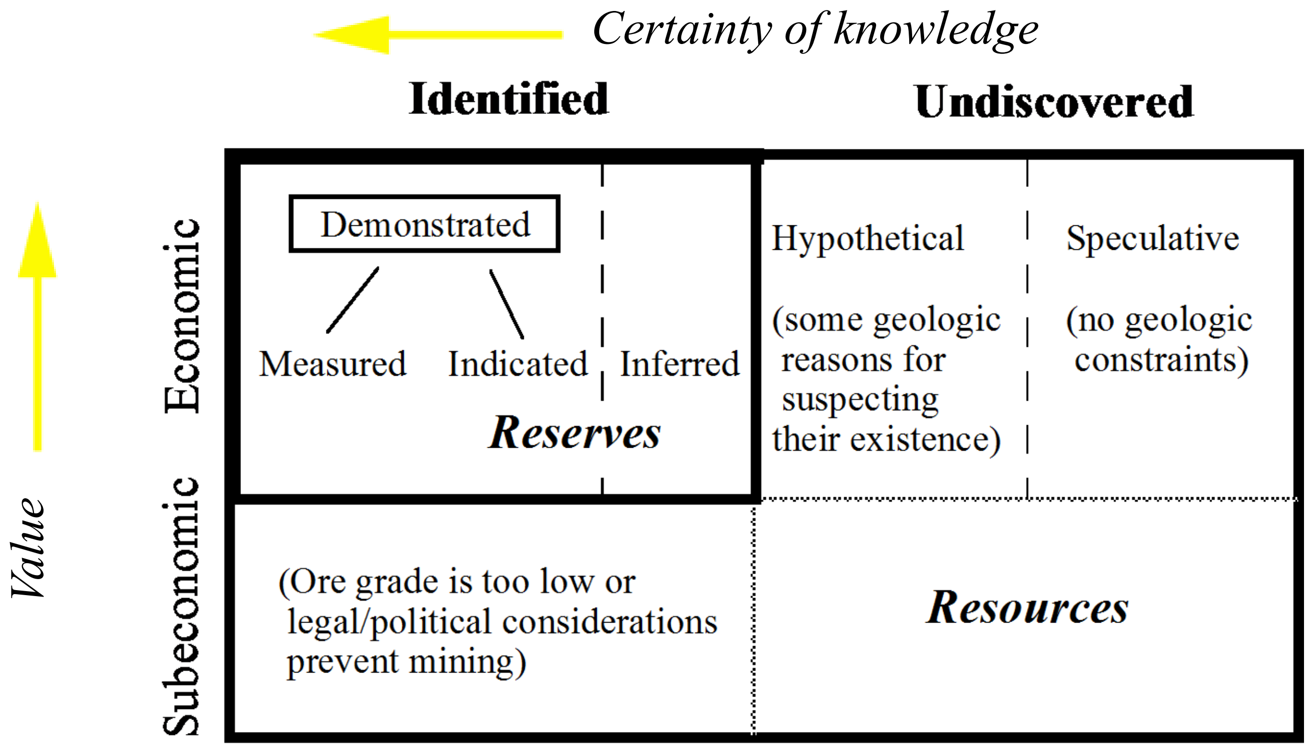
To a geologist – ore deposits are the result of fundamental processes

1) partial melting
2) immiscibility
3) fractional crystallization
4) fluid exsolution – pressure quench
5) phase separation (boiling)
6) fluid mixing
7) redox/neutralization Eh - pH

USGS


Surface Processes
Fresh
Marine
Sabka
Evaporite
Placers Au, PGE, Sn, REE
Laterites Fe, Al, Au
Banded Iron Form.
Mn nodules + bogs
Supergene enrichment
Oxidation
Reduction
Roll front
Unconformity
U, V, Cu, PGE
Sedimentary Basins
Stratabound
Pb, Zn, Cu, Ag
Basinal Brines
Earth's Crust
Shallow circulating groundwater/seawater
connate/diagenetic brines
deeply circulating groundwater
structural dislocation
metamorphic dehydration
Seawater/ Meteoric Water
Hydrothermal Ore Fluid
Magmatic Water
Wall rock
Leaching
Volcanic centers
Marine
Massive sulfide
Cu, Zn, Pb, Ba, Au, Ag
Continental
Veins - Cu, As, Zn, Pb, Au,Ag
Geothermal
Hot springs veins, sinters
Au, Ag, Hg, As, Sb, Tl
Metamorphic
Devolatization
Skarns
Fe,W,Cu,Au,Ag
Zn-Pb,Mo,W,U
Shear Veins
quartz-carbonate
Au, As, W
Pegmatites
Sn,Be,Li,U,B mica, quartz feldspar
Porphyry
Cu,Mo, Au,Ag
Sn-W
IOCG
Fe, Cu, Au, ± U, REE
Ti (anorthosite)
Exsolution
Source variations: water, volatiles metals, redox T, P, % melting
Crystal float
Magma Crystallization
Pressure quench
Partial melting
Immiscible liquid
Sulfide melt
Ni-Cu-PGE (komatiite, gabbro)
Oxide melt
Crystal cumulate
Direct emplacement
Kimberlites
Carbonatites
Diatremes
Cu,Au,REE,U
Volatile rich
Fe-P (diorite, syenite)
Cr (peridotite)
L. Meinert 2008

To economist ore deposits can be viewed as reserves and resources, as a function of supply and demand

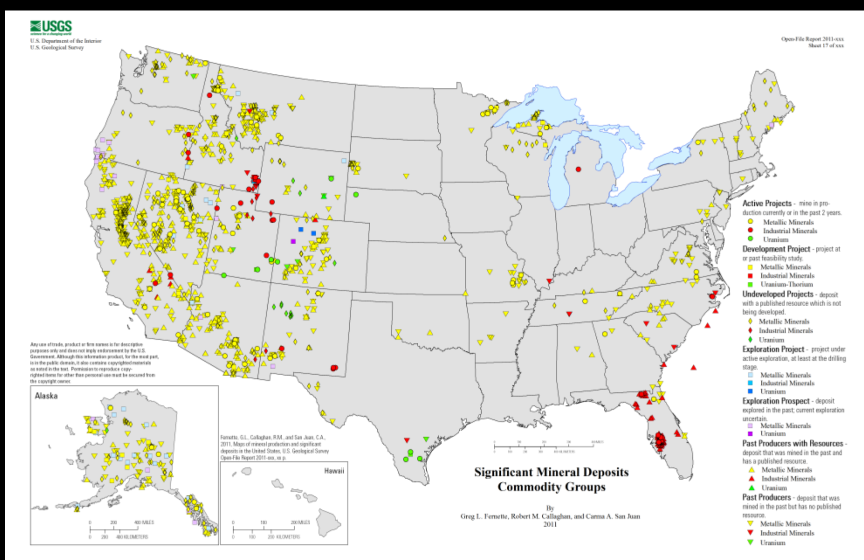


- Typically have about 20 years of reserves due to economics, taxation
- Mineral resources are finite (but very large compared to scale of use)
- Price, not supply, controls availability
- Resources have a place value, i.e., occur in specific locations, decide if to produce but not where

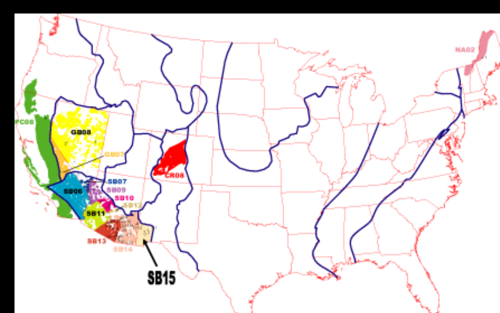
USGS

Inventory vs Assessment

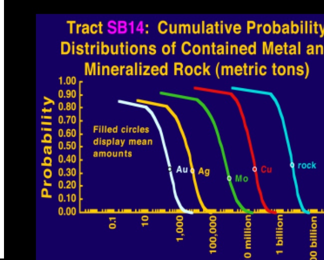
Inventory	Assessment
Identified resources	Undiscovered resources
Near- and medium-term supply	Long-term potential supply
Often classified by commodity	Classified by mineral deposit type
Important first step for assessment	Qualitative and Quantitative



Where



How much



Probabilistic

USGS

Mineral Resource Assessment Methodology

The Assessment: A 3-Part Process

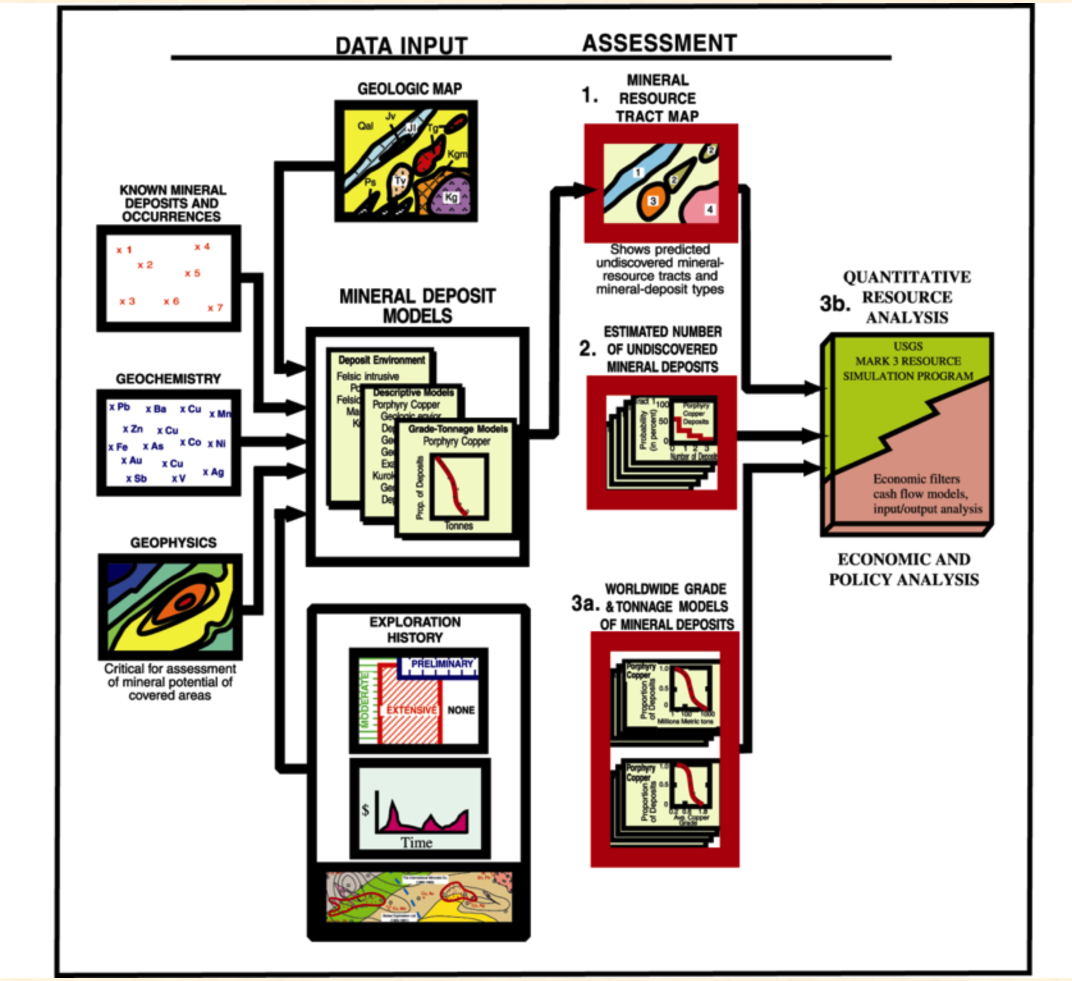
<u>Qualitative</u>

1. Delineate permissive tracts for occurrence of each deposit type

<u>Quantitative</u>

2. Estimate number of undiscovered deposits in each tract

3. Apply global grade and tonnage models to estimate quantity and quality of undiscovered contained metal/resource.



Reference

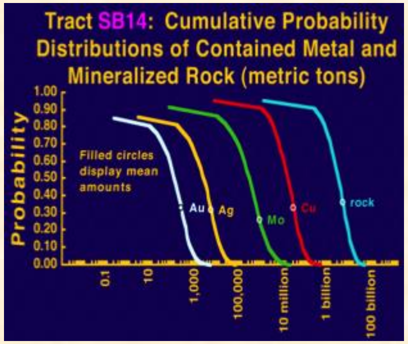
Singer, D.A., 1993, Basic concepts in three-part quantitative assessments of undiscovered mineral resources: Nonrenewable Resources, v. 2, no. 2, p. 69-81.

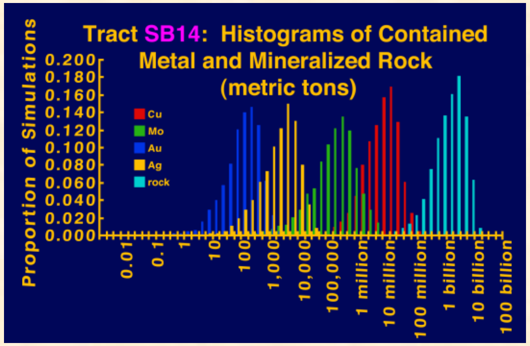
PART 3: Estimate quality and quantity of undiscovered contained metal

- ***Estimates of number of undiscovered deposits are combined with data from grade & tonnage models to provide estimates of contained metal using Monte Carlo simulation (Mark3)***

    - Mark3 computes populations of theoretical ore and metal endowments for each deposit tract that are consistent with estimated deposits and grade-tonnage models

    - This allows for the translation of resource assessments into the language that economists and decision makers can understand -- **money**





Global Mineral Resource Assessment

CCOP Workshop 2006
Kunming, China

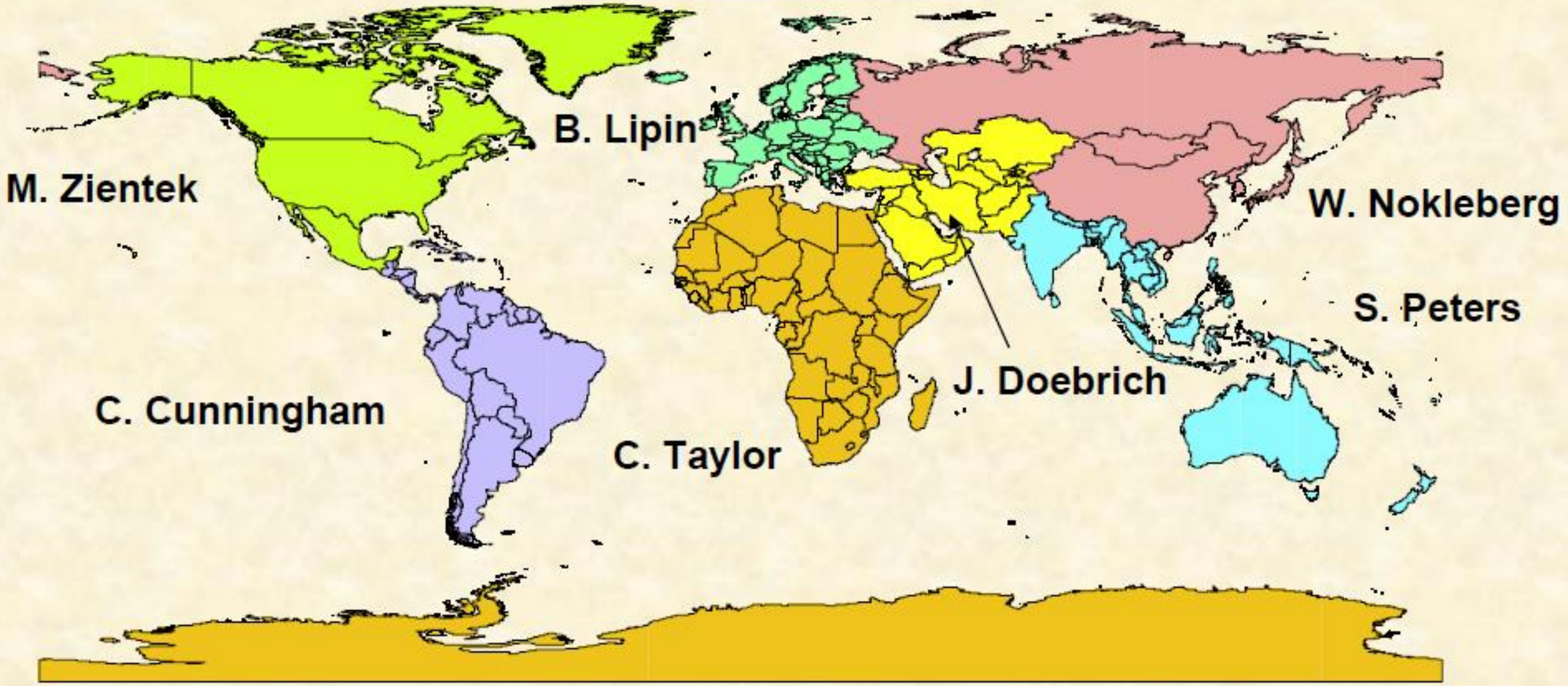
CCOP Workshop 2010
Busan, S Korea

U.S. Department of the Interior
U.S. Geological Survey

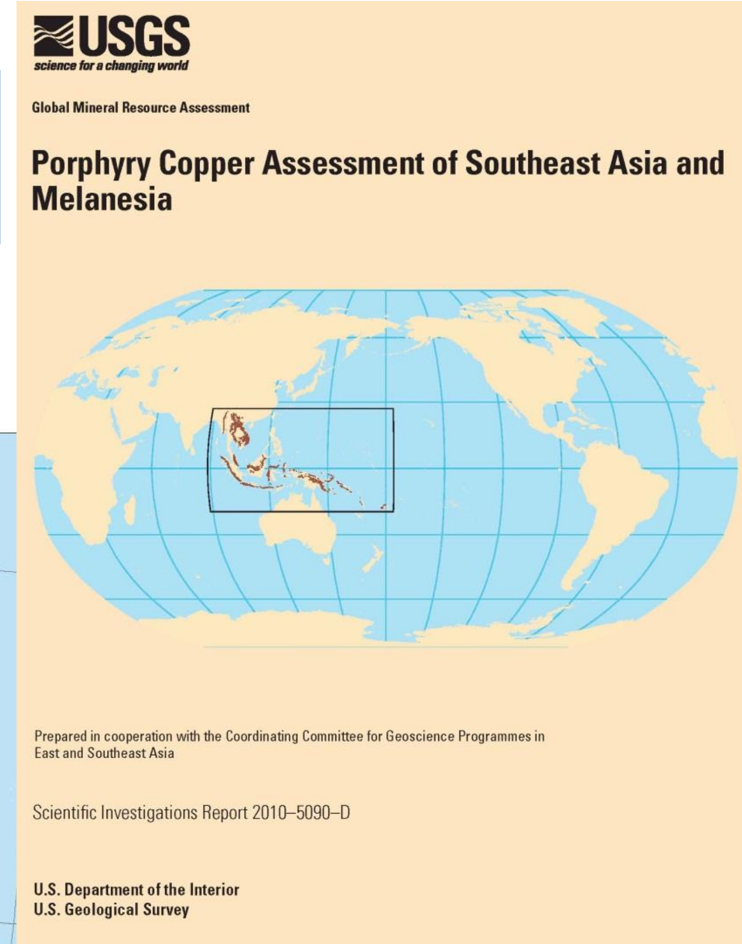
Global Mineral Resource Assessment

The Global Mineral Resource Assessment is being conducted on a **regional multinational basis** with the **cooperative participation** of interested national and international geoscience organizations using **available** geologic and mineral resource **information**

7 GMRAP Regions



Indonesia is included in a report on parts of Southeast Asia and Melanesia


USGS
science for a changing world

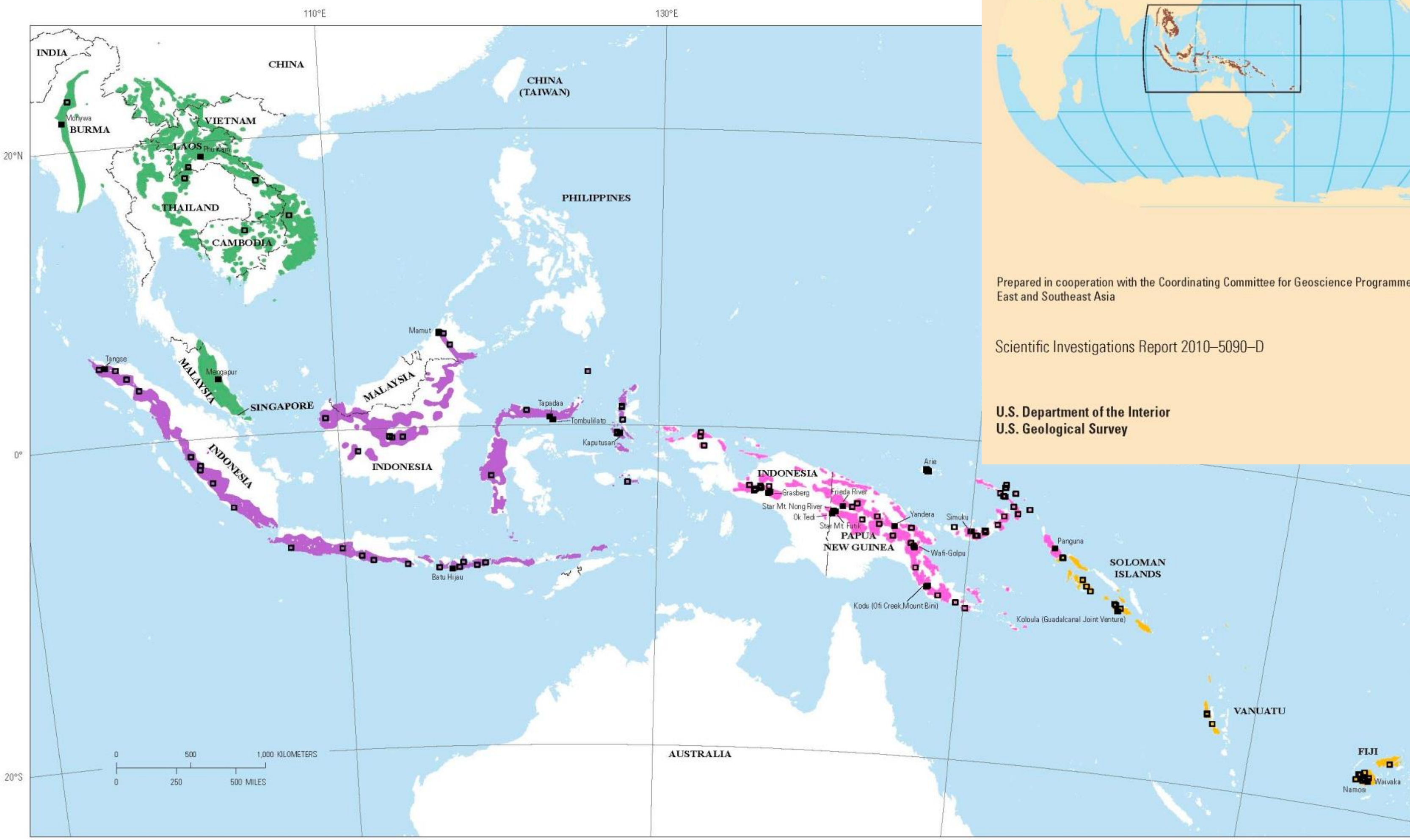
Global Mineral Resource Assessment

Porphyry Copper Assessment of Southeast Asia and Melanesia

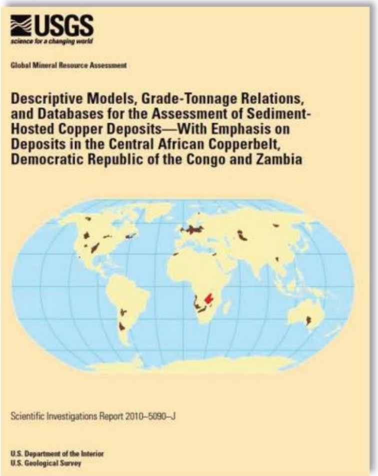
Prepared in cooperation with the Coordinating Committee for Geoscience Programmes in East and Southeast Asia

Scientific Investigations Report 2010–5090–D

U.S. Department of the Interior
U.S. Geological Survey



Global Mineral Resource Assessment Project



In response to the growing demand for information on the global mineral-resource base, the U.S. Geological Survey Mineral Resources Program is completing its Global Mineral Resource Assessment Project (GMRAP), a cooperative international project started in 2002 to assess the world's undiscovered nonfuel mineral resources. The project emphasizes the most important types of mineral deposits for world supply of copper, platinum-group elements (PGE), and potash.

USGS conducts national and global assessments of resources (mineral, energy, water, biologic) to provide science in support of decisionmaking. Mineral resource assessments provide a synthesis of available information about where mineral deposits are known and suspected in the Earth's crust, what commodities may be present, and estimates of amounts of undiscovered resources that may be present.

Published GMRAP Reports

Porphyry copper assessment of Southeast Asia and Melanesia
Porphyry copper assessment of the Mesozoic of East Asia--China, Vietnam, North Korea, Mongolia, and Russia
Porphyry copper assessment of the Tibetan Plateau, China
Porphyry copper assessment of British Columbia and Yukon Territory, Canada
Porphyry copper assessment of Mexico
Quantitative mineral resource assessment of copper, molybdenum, gold, and silver in undiscovered porphyry copper deposits in the Andes Mountains of South America
Descriptive models, grade-tonnage relations, and databases for the assessment of sediment-hosted copper deposits—With emphasis on deposits in the Central Africa Copperbelt, Democratic Republic of the Congo and Zambia
Sandstone copper assessment of the Chu-Sarysu Basin, Central Kazakhstan
Dzhezkazgan and associated sandstone copper deposits of the Chu-Sarysu Basin, central Kazakhstan: Society of Economic Geologists, Inc., Special Publication 16, p. 303-328.
Economic filters for evaluating porphyry copper deposit resource assessments using grade-tonnage deposit models, with examples from the U.S. Geological Survey Global Mineral Resource Assessment

Pending GMRAP Reports

- Porphyry copper assessment of Central America and the Caribbean Basin
- Porphyry copper assessment of Europe
- Porphyry copper assessment of eastern Australia
- Porphyry copper assessment of western central Asia [Tectonic and geologic setting of porphyry copper deposits in western central Asia, with a special section on the application of satellite data to alteration mapping]
- Porphyry copper assessment of East and Southeast Asia—The Philippines, Taiwan (Republic of China), and Japan
- Porphyry copper assessment of the Central Tethys Region—Turkey, Iran, parts of Pakistan and Afghanistan, Armenia, and Azerbaijan
- Porphyry copper assessment of northeast Asia—Far east Russia and northernmost China
- Porphyry copper assessment of the Central Asian Orogenic Belt and Eastern Tethysides—China, Mongolia, Kazakhstan, Russia, India, and Pakistan
- Regional mapping of hydrothermally altered igneous rocks along the Urumieh-Dokhtar, Chagai, and Alborz belts of western Asia using Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) data and Interactive Data Language (IDL) Logical Operators—A tool for porphyry copper exploration and assessment

US Soil Map – Sample Density

The Conterminous U.S. Landscape Geochemistry project has recently sampled soils at 4,860 sites shown in Figure 1. Three samples were collected at each site. In addition to chemical analyses, we have performed quantitative mineralogy by x-ray diffraction and Rietveld refinement calculations for all A-horizon and C-horizon samples.

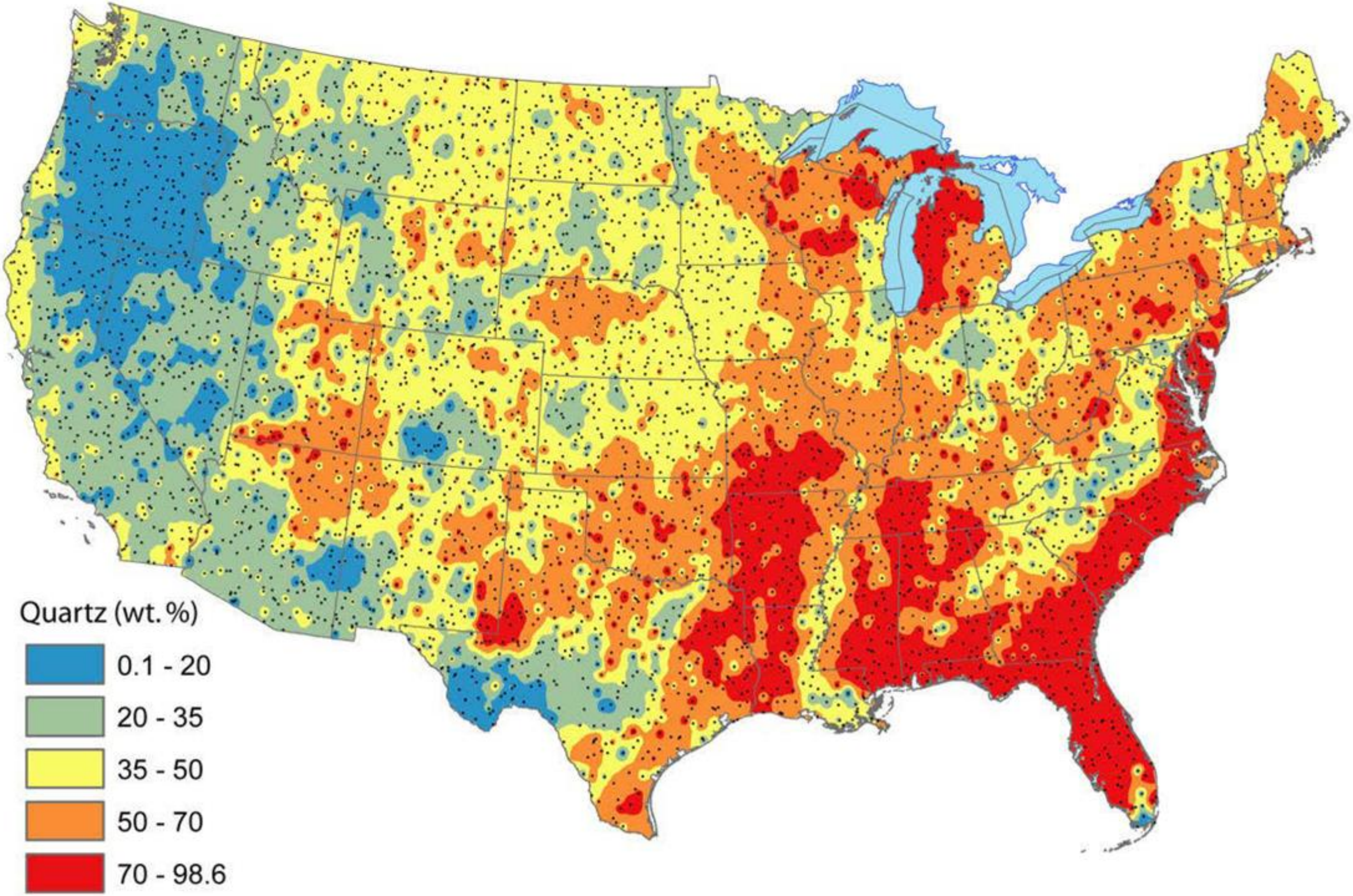
Figure 1

1 Upper 5 cm

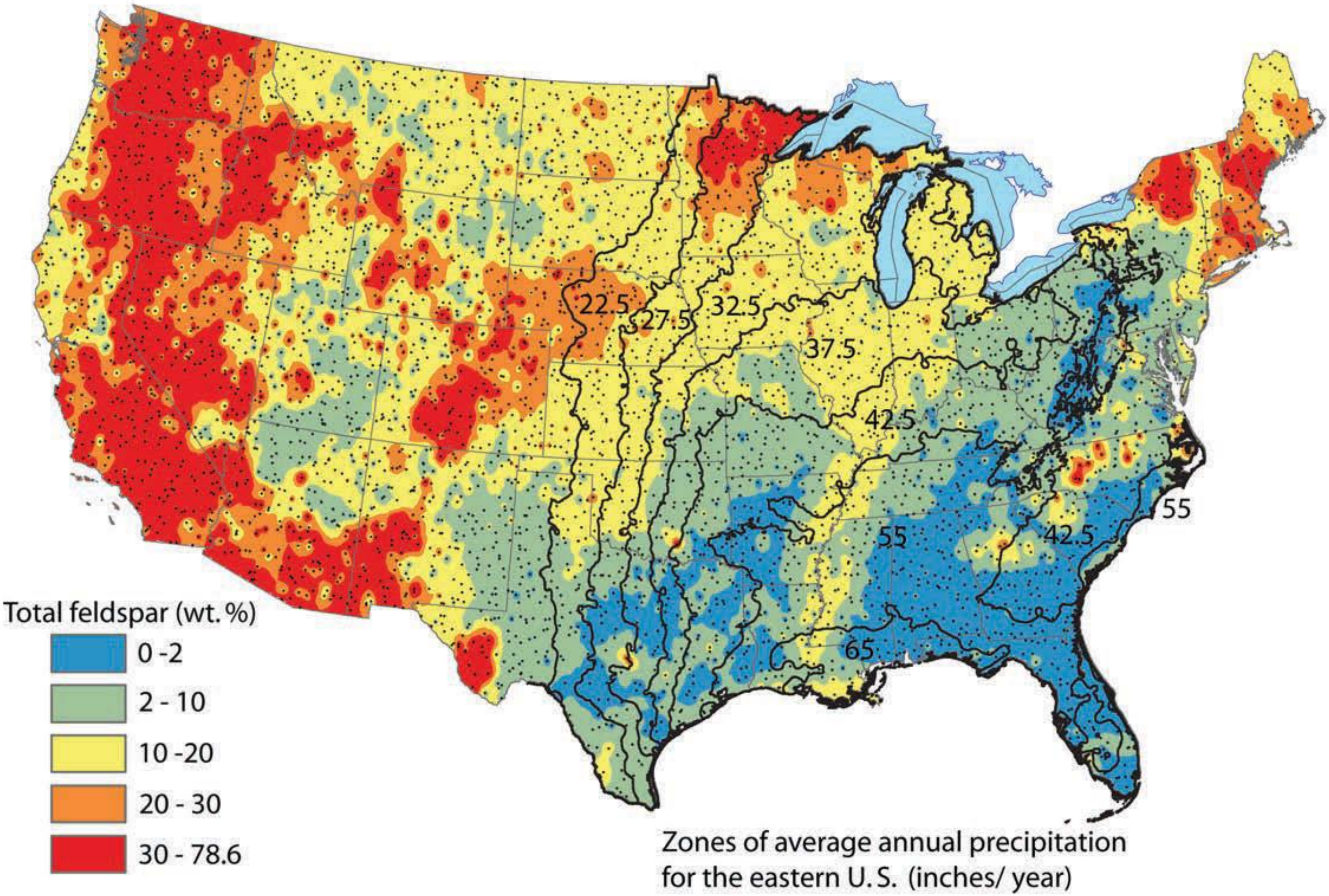
2 Composite of A-horizon

3 C-horizon: Fresh to slightly altered parent material. Generally from ~ 1m depth

Quartz content of C-horizon soil



Total feldspar in C-horizon soil



Tracking Resources and Estimating Future Supplies

Larry Meinert
Mineral Resources Program, USGS

Oct. 29, 2013 Pardee P12: Resourcing Future Generations