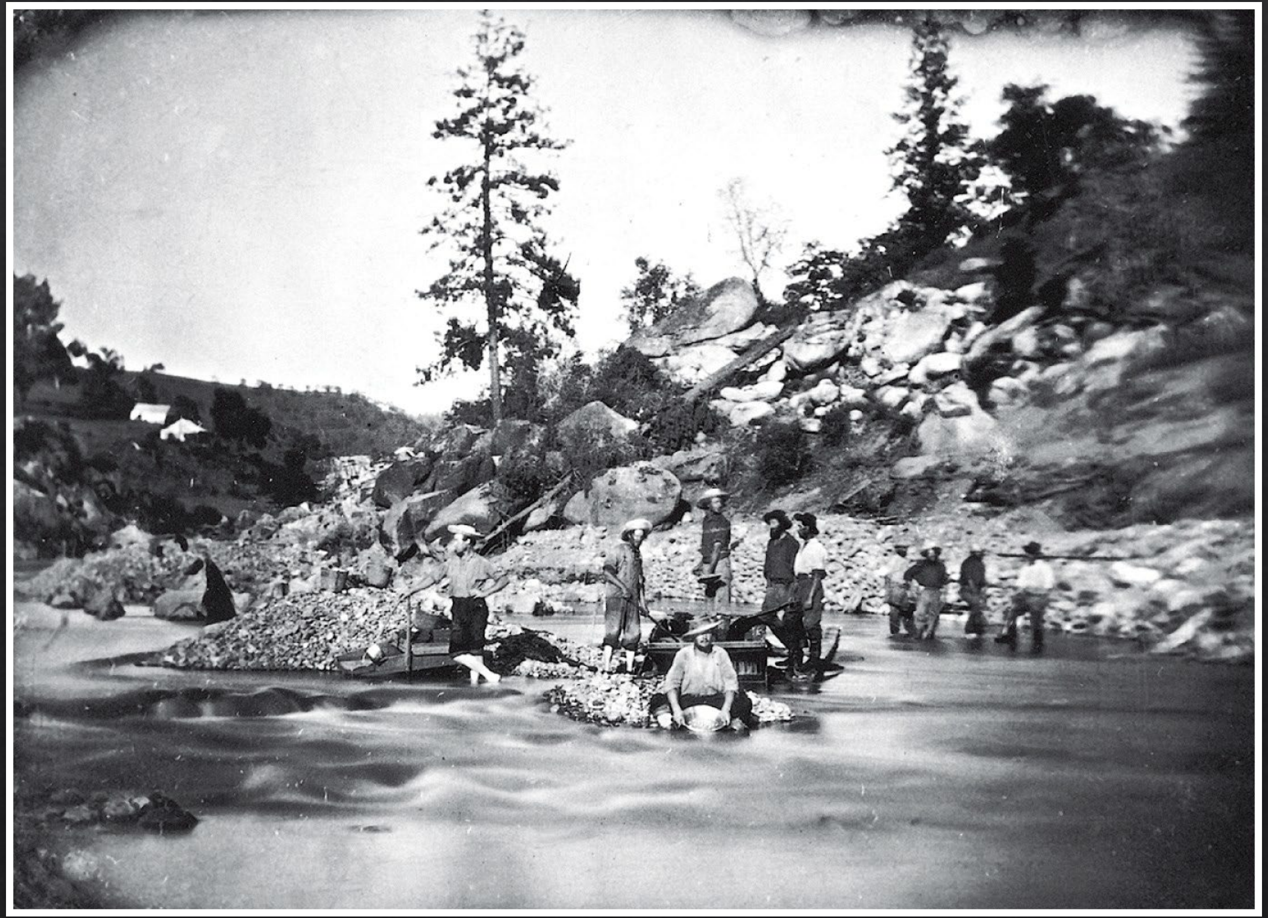
Economic Geology in Iowa and Beyond… Minerals and Rocks edition

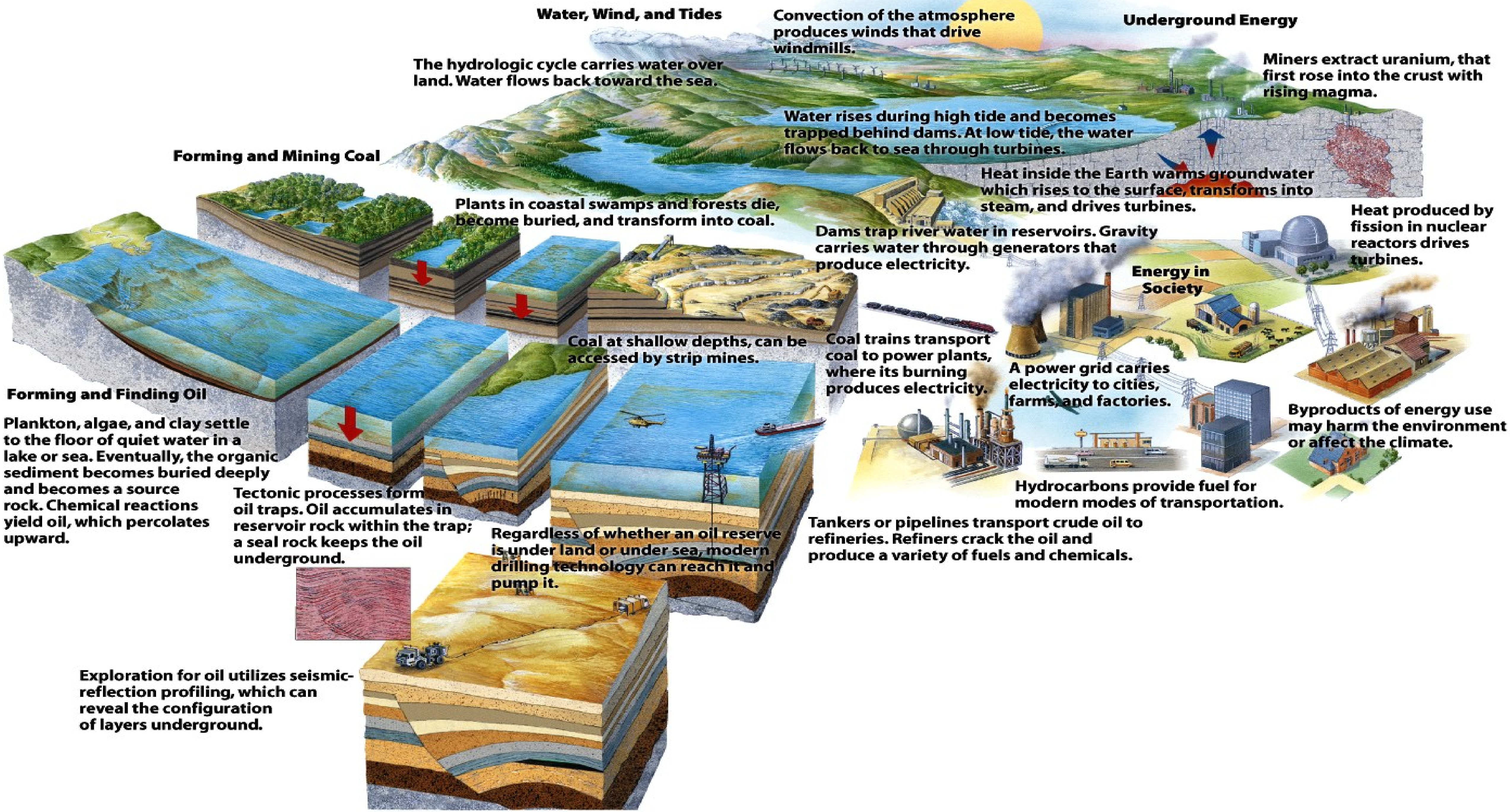
With borrowed images and slides from Marshak's Earth – Earth a Portrait of a Planet

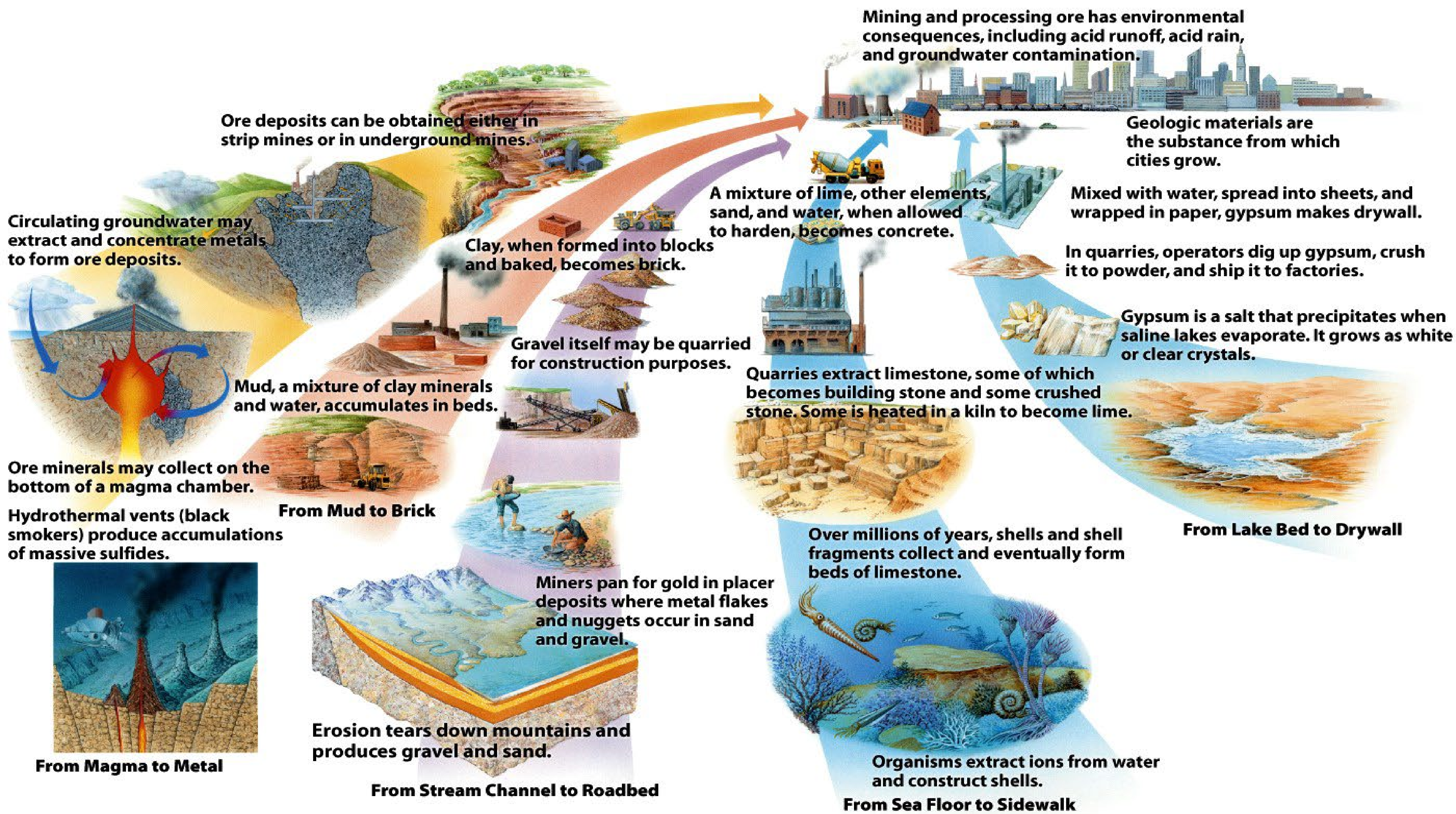
and Ray Anderson's 2013 Iowa Academy of Science Talk

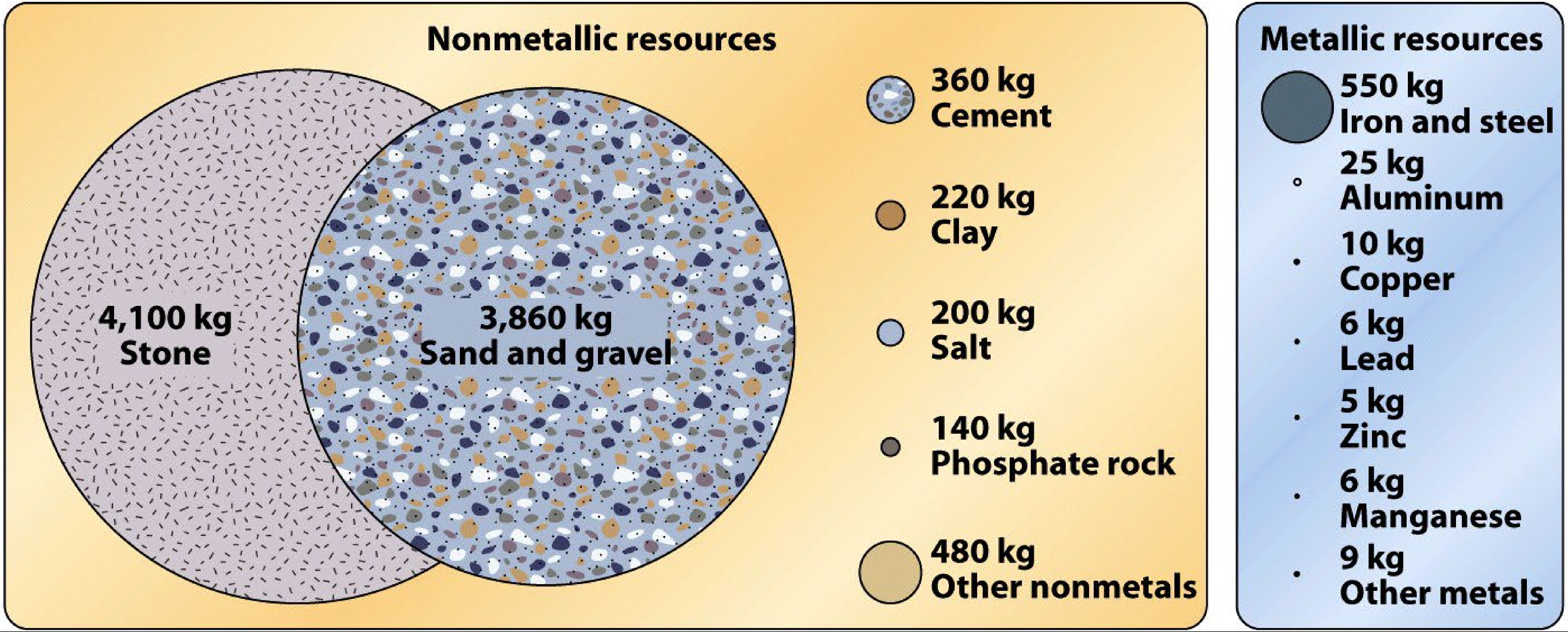
Natural Resources

If you cannot grow it, then you have to mine it.




Water, Wind, and Tides
Convection of the atmosphere produces winds that drive windmills.
Underground Energy
The hydrologic cycle carries water over land. Water flows back toward the sea.
Miners extract uranium, that first rose into the crust with rising magma.
Water rises during high tide and becomes trapped behind dams. At low tide, the water flows back to sea through turbines.
Forming and Mining Coal
Heat inside the Earth warms groundwater which rises to the surface, transforms into steam, and drives turbines.
Plants in coastal swamps and forests die, become buried, and transform into coal.
Heat produced by fission in nuclear reactors drives turbines.
Dams trap river water in reservoirs. Gravity carries water through generators that produce electricity.
Energy in Society
Coal at shallow depths, can be accessed by strip mines.
Coal trains transport coal to power plants, where its burning produces electricity.
A power grid carries electricity to cities, farms, and factories.
Forming and Finding Oil
Plankton, algae, and clay settle to the floor of quiet water in a lake or sea. Eventually, the organic sediment becomes buried deeply and becomes a source rock. Chemical reactions yield oil, which percolates upward.
Byproducts of energy use may harm the environment or affect the climate.
Tectonic processes form oil traps. Oil accumulates in reservoir rock within the trap; a seal rock keeps the oil underground.
Hydrocarbons provide fuel for modern modes of transportation.
Tankers or pipelines transport crude oil to refineries. Refiners crack the oil and produce a variety of fuels and chemicals.
Regardless of whether an oil reserve is under land or under sea, modern drilling technology can reach it and pump it.
Exploration for oil utilizes seismic-reflection profiling, which can reveal the configuration of layers underground.


Mining and processing ore has environmental consequences, including acid runoff, acid rain, and groundwater contamination.
Geologic materials are the substance from which cities grow.
Ore deposits can be obtained either in strip mines or in underground mines.
Circulating groundwater may extract and concentrate metals to form ore deposits.
Clay, when formed into blocks and baked, becomes brick.
A mixture of lime, other elements, sand, and water, when allowed to harden, becomes concrete.
Mixed with water, spread into sheets, and wrapped in paper, gypsum makes drywall.
In quarries, operators dig up gypsum, crush it to powder, and ship it to factories.
Gypsum is a salt that precipitates when saline lakes evaporate. It grows as white or clear crystals.
Gravel itself may be quarried for construction purposes.
Quarries extract limestone, some of which becomes building stone and some crushed stone. Some is heated in a kiln to become lime.
Mud, a mixture of clay minerals and water, accumulates in beds.
Ore minerals may collect on the bottom of a magma chamber.
From Mud to Brick
Hydrothermal vents (black smokers) produce accumulations of massive sulfides.
From Lake Bed to Drywall
Over millions of years, shells and shell fragments collect and eventually form beds of limestone.
Miners pan for gold in placer deposits where metal flakes and nuggets occur in sand and gravel.
Erosion tears down mountains and produces gravel and sand.
From Magma to Metal
Organisms extract ions from water and construct shells.
From Stream Channel to Roadbed
From Sea Floor to Sidewalk


Nonmetallic resources
4,100 kg
Stone
3,860 kg
Sand and gravel
360 kg
Cement
220 kg
Clay
200 kg
Salt
140 kg
Phosphate rock
480 kg
Other nonmetals
Metallic resources
550 kg
Iron and steel
25 kg
Aluminum
10 kg
Copper
6 kg
Lead
5 kg
Zinc
6 kg
Manganese
9 kg
Other metals

Metal	Mineral Name	Chemical Formula
Copper	Chalcocite	Cu_2S
	Chalcopyrite	$CuFeS_2$
	Bornite	Cu_5FeS_4
	Azurite	$Cu_3(CO_3)_2(OH)_2$
	Malachite	$Cu_2(CO_3)(OH)_2$
Iron	Hematite	Fe_2O_3
	Magnetite	Fe_3O_4
Tin	Cassiterite	SnO_2
Lead	Galena	PbS
Mercury	Cinnabar	HgS
Zinc	Sphalerite	ZnS
Aluminum	Kaolinite	$Al_2Si_2O_5(OH)_4$
	Corundum	Al_2O_3
Chrome	Chromite	$(Fe,Mg)(Cr,Al,Fe)2O_4$
Nickel	Pentlandite	$(Ni,Fe)_9S_8$
Titanium	Rutile	TiO_2
	Ilmenite	$FeTiO_3$
Tungsten	Sheelite	$CaWO_4$
Molybdenum	Molybdenite	MoS_2
Magnesium	Magnesite	$MgCO_3$
	Dolomite	$CaMg(CO_3)_2$
Manganese	Pyrolusite	MnO_2
	Rhodochrosite	$MnCO_3$

Metal	World Resources	U.S. Resources
Iron	120	40
Aluminum	330	2
Copper	65	40
Lead	20	40
Zinc	30	25
Gold	30	20
Platinum	45	1
Nickel	75	less than 1
Cobalt	50	less than 1
Manganese	70	0
Chromium	75	0

National Security

"RELIABLE ACCESS TO CRITICAL MINERALS IS A MATTER OF BOTH ECONOMIC AND GEOSTRATEGIC IMPORTANCE TO THE UNITED STATES. ALTHOUGH CONCERN ABOUT ACCESS TO MINERALS WAXES AND WANES, IT IS RISING NOW DUE TO INCREASING DEMAND, NEW COMPETITORS CAPTURING LARGE MARKET SHARES AND OTHER TRENDS THAT DEFY EASY PREDICTION. THESE SAME TRENDS CAN INTERFERE WITH FOREIGN AND DEFENSE POLICY GOALS AND GIVE MINERAL SUPPLIERS EASY LEVERAGE OVER THE UNITED STATES AND OTHER COUNTRIES RELIANT ON GLOBAL SUPPLY CHAINS."

CHRISTINE PARTHEMORE
FORMER FELLOW
CENTER FOR A NEW AMERICAN SECURITY

Top 10 Standard Materials
Used by Department of Defense

#	Material	Regular DoD Demand in STONS/YR
1	ALUMINUM METAL	275,219.8
2	COPPER	105,625.8
3	LEAD	88,464.8
4	FLUORSPAR ACID GRADE	56,544.5
5	ZINC	51,085.5
6	RUBBER (NATURAL)	29,490.3
7	MANGANESE ORE CHEM/METAL GRADE	25,041.8
8	NICKEL	17,311.8
9	CHROMIUM FERRO (FERROCHROMIUM)	9,667.8
10	CHROMITE ORE (ALL GRADES)	9,630.5

Source: "Reconfiguration of the National Defense Stockpile Report to Congress," U.S. Department of Defense, April 2009.

Rhenium
Nickel

+

Lanthanum
Gadolinium
Yttrium

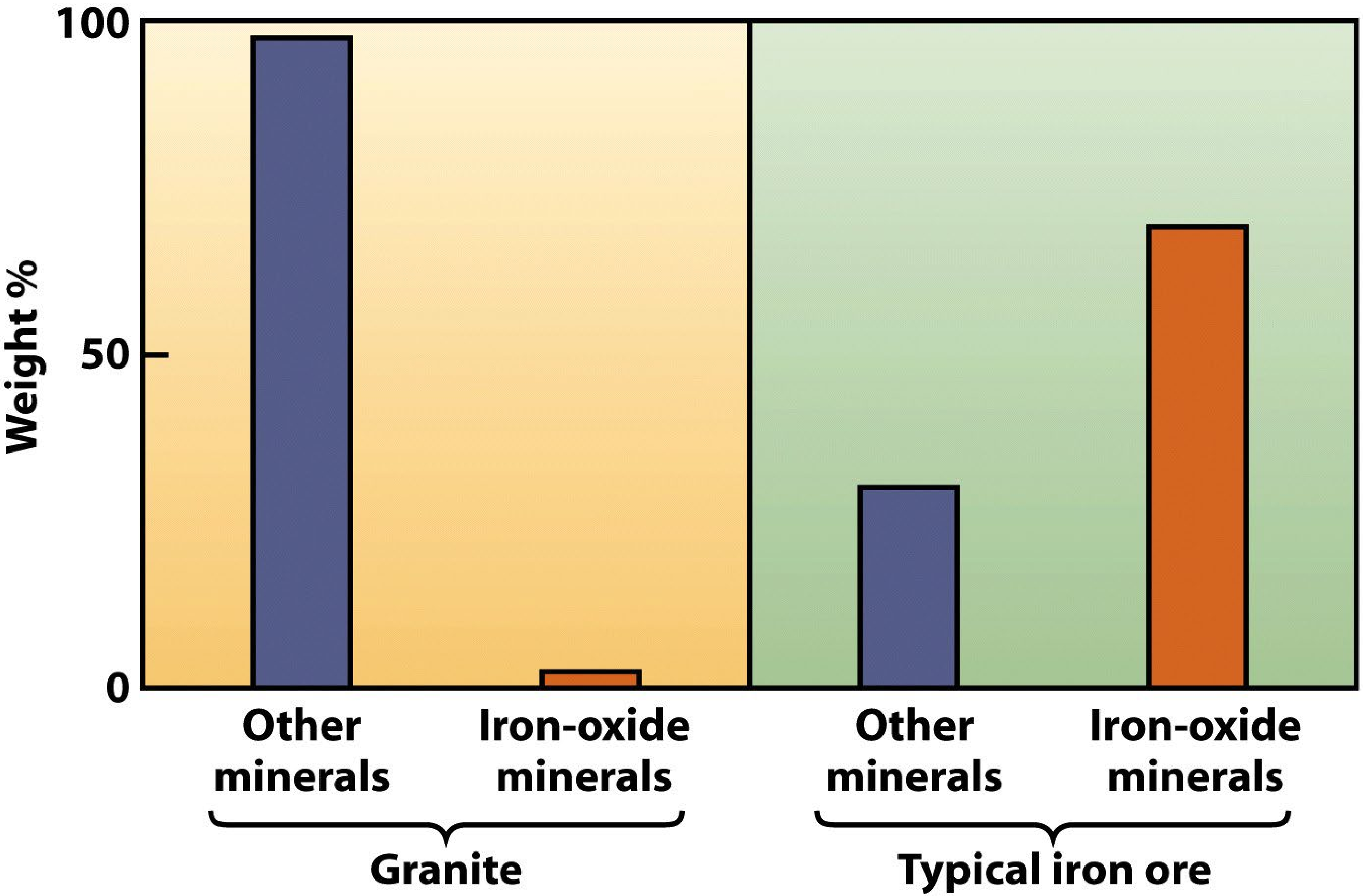
+

Aluminum
Copper

+

Manganese
Molybdenum

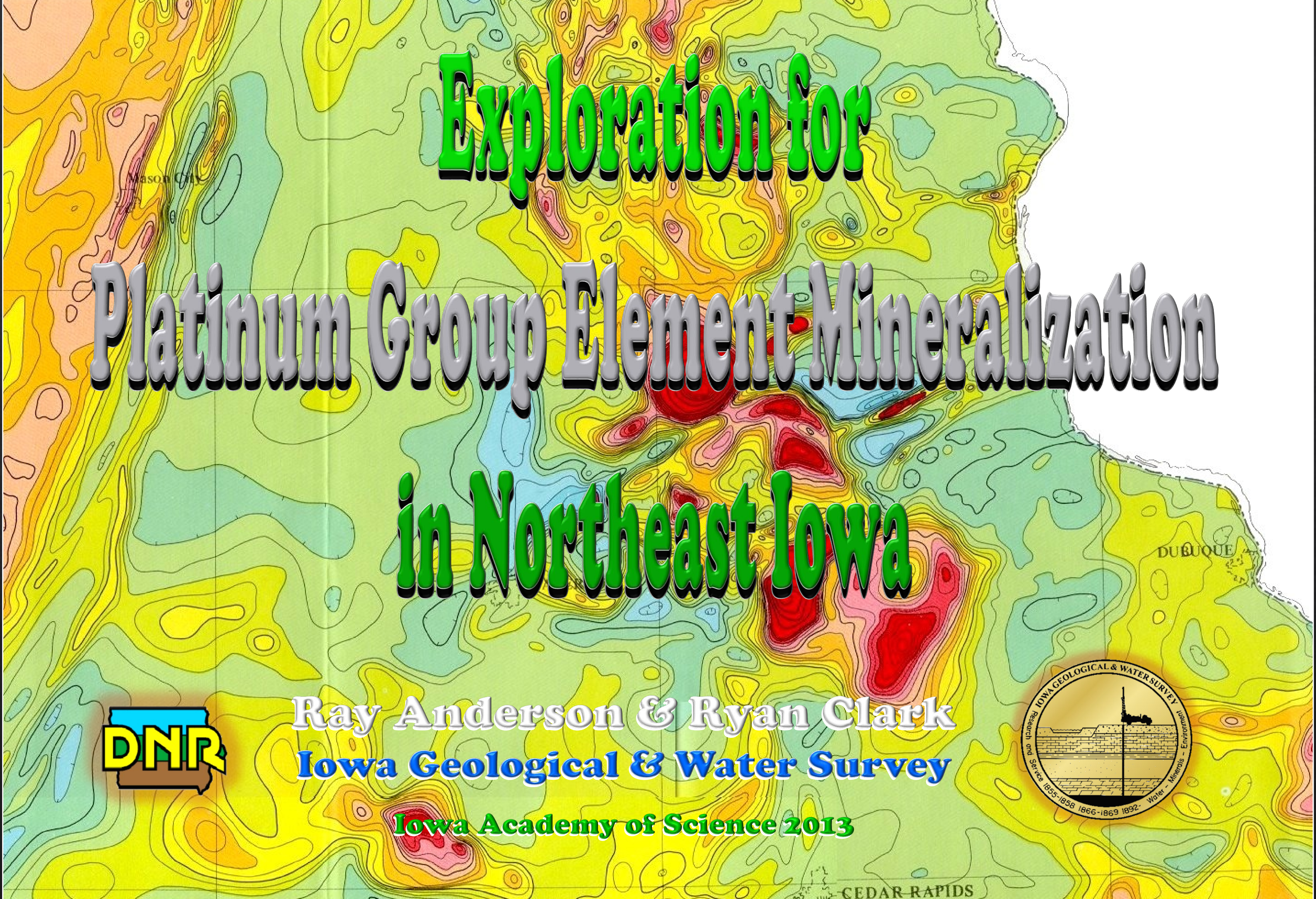
= Nearly 750,000 **Tons** of Minerals Annually


100
50
0
Weight %
Other minerals
Iron-oxide minerals
Other minerals
Iron-oxide minerals
Granite
Typical iron ore

Exploration for Platinum Group Element Mineralization in Northeast Iowa

Ray Anderson & Ryan Clark
Iowa Geological & Water Survey

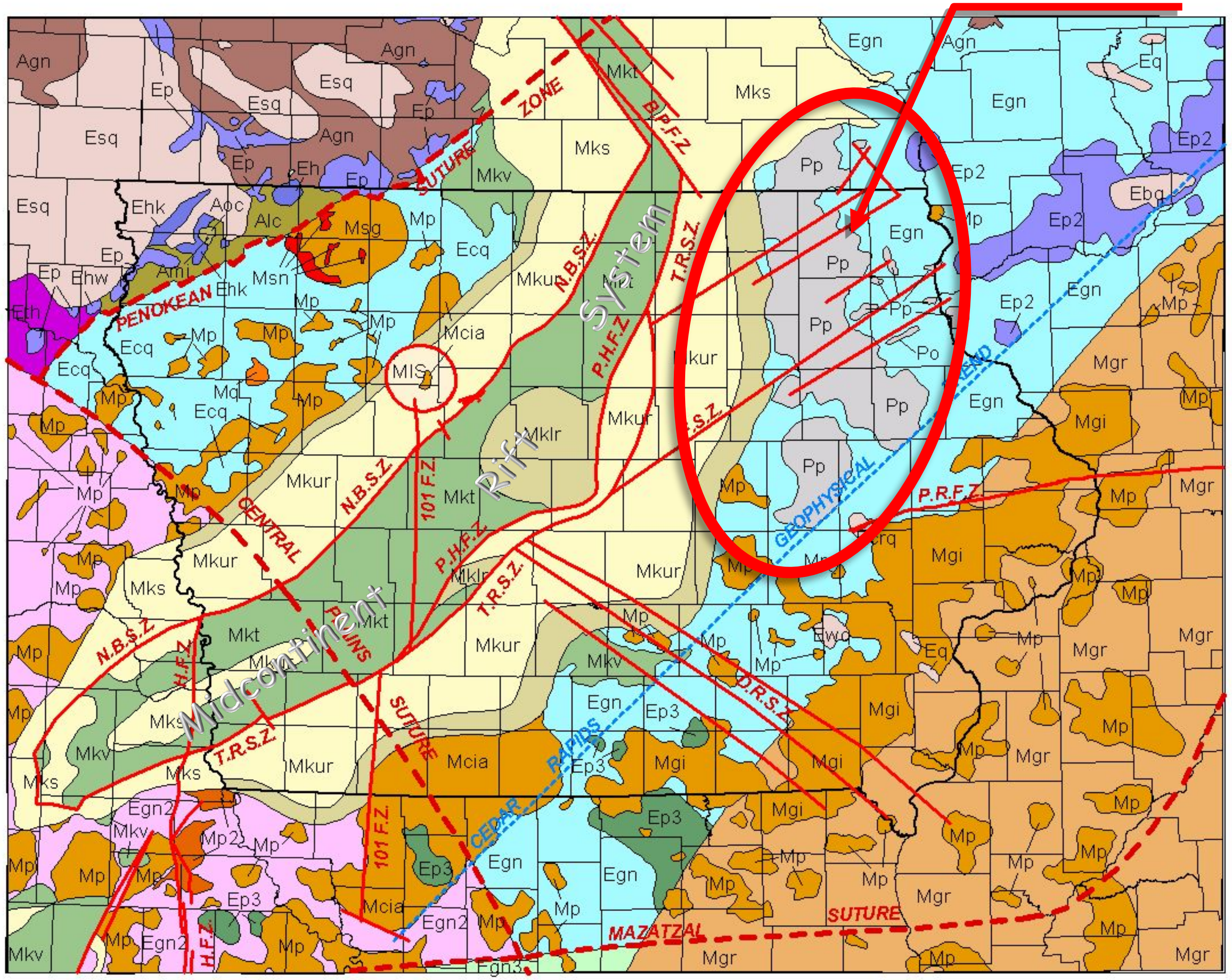
Iowa Academy of Science 2013



Geology of the Precambrian Surface of Iowa and surrounding area

Raymond R. Anderson - 1999

Northeast Iowa Plutonic Complex



LEGEND

(ages given in millions of years - Ma)

PROTEROZOIC (2500 - 530 Ma)

GRENVILLE INTERVAL (1350-1000 Ma)
- (Mks) Keweenawan Clastic Sedimentary Rocks
  - (Mkur) Keweenawan Upper Red Clastic Group
  - (Mklr) Keweenawan Lower Red Clastic Group
- (Mkv) Keweenawan Volcanic / Plutonic Rocks
  - (Mkt) Keweenawan Thor Volcanic Group

SOUTHERN GRANITE / RHYO. INTERVAL (1380 - 1310 Ma)
- (Mp2) Granitic plutons

EASTERN GRANITE / RHYOL. INTERVAL (1500 -1430 Ma)
- (Mgr) Rhyolite and granitic plutons
- (Mp) Granitic plutons
  - (Mq) Quimby granite (1433 ± 6 Ma)
  - (Mgi) Green Island Plutonic Group (1485 ± 10 Ma)
  - (Msn) Spencer Norite
  - (Msg) Spencer Granite (1373 ± 7 Ma)

BARABOO INTERVAL (1620 - 1500 Ma)
- (Eq) quartzite dominated
  - (Ebq) Baraboo Quartzite
  - (Esq) Sioux Quartzite
  - (Ecrq) Cedar Rapids Quartzite
  - (Ewq) Washington County Quartzite

MAZATZAL INTERVAL (1650-1620 Ma)
- (Ep3) Granitic plutons dominant
- (Egn3) Gneiss dominant

CENTRAL PLAINS INTERVAL (1800-1700 Ma)
- (Egn2) Gneiss and granite dominant

PENOKEAN INTERVAL (2100-1800 Ma)

Penokean Orogenic Belt
- (Ep) Post-orogenic granitic plutons
  - (Ehk) Hull Keratophyre (1782 ± 4 Ma)
  - (Eh) Harris Granite (1804 ± 17 Ma)
  - (Ehw) Hawarden Granite
- (Ep2) Late-stage granitic plutons
- (Egn) Orogenic gneiss and granite
  - (Ecq) Camp Quest Gneiss (2065 ± 10 Ma)

Trans-Hudson Orogenic Belt
- (Eth) Ganite and gneiss dominant

ARCHEAN (>2500 Ma)

- (Alc) Lyon County Gneiss (2523 ± 5 Ma)
- (Ami) Matlock Banded Iron Formation
- (Aoc) Otter Creek Mafic Complex (2890 ± 90 Ma)
- (Agn) Early to Middle Archean gneiss and migmatite terrane

ROCKS OF UNCERTAIN AFFINITIES
- (Mcia) Central Iowa Arch Granites
- (Po) Osborne Mafic Complex
- (Pp) Northeast Iowa Plutonic Complex

- (MIS) Late Cretaceous (73.8 ± 3 Ma) Manson Impact Strucuture

- known or inferred faults
- Proterozoic sutures
- geophysical trend

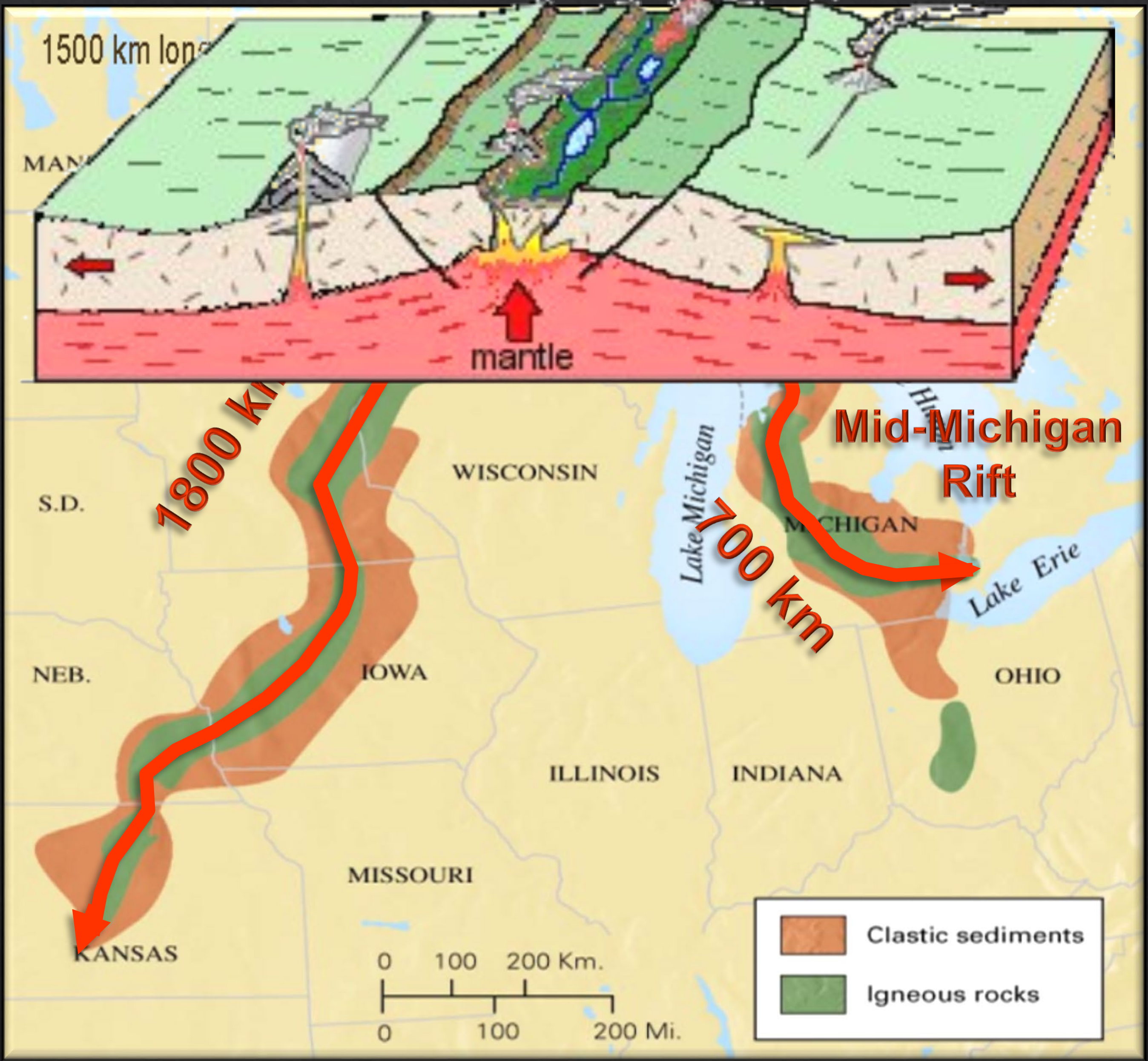
key to mapped faults

N.B.F.Z.	N.B.F.Z. Northern Boundary Falut Zone	P.R.F.Z.	Plum River Fault Zone
T.R.S.Z.	Thurman-Redfield Fault Zone	D.R.F.Z.	Des Moines River Fault Zone
P.H.F.Z.	Perry-Hampton Fault Zone	101 F.Z.	101 Fault Zone
B.P.F.Z.	Belle Plaine Fault Zone	F.S.Z.	Fayette Structural Zone
H.F.Z.	Humboldt Fault Zone		

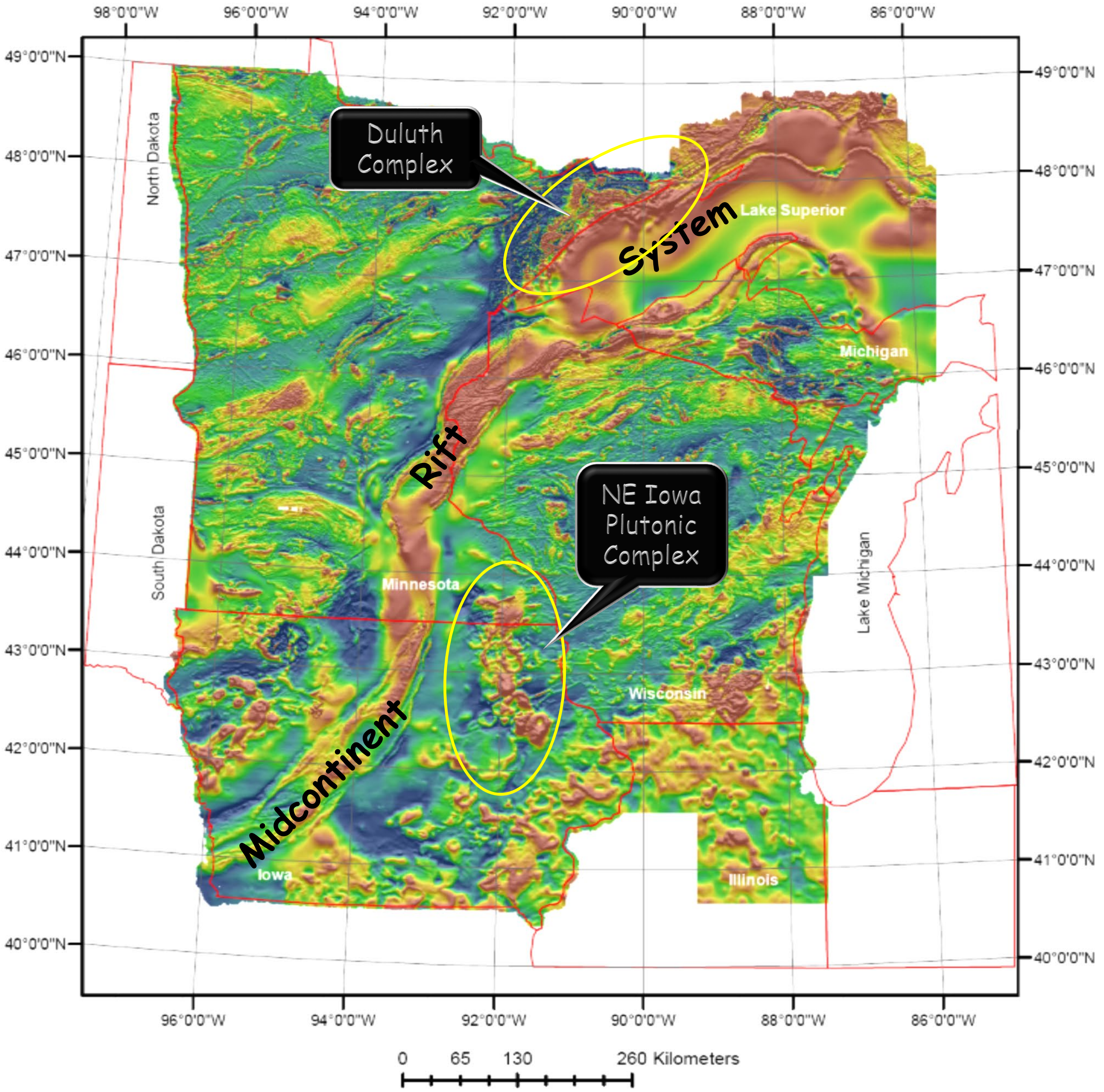
N W E S

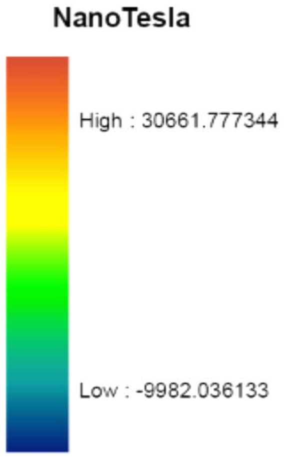
0 100 Miles

The Midcontinent Rift System



Shaded-Relief Total Magnetic Intensity Anomaly

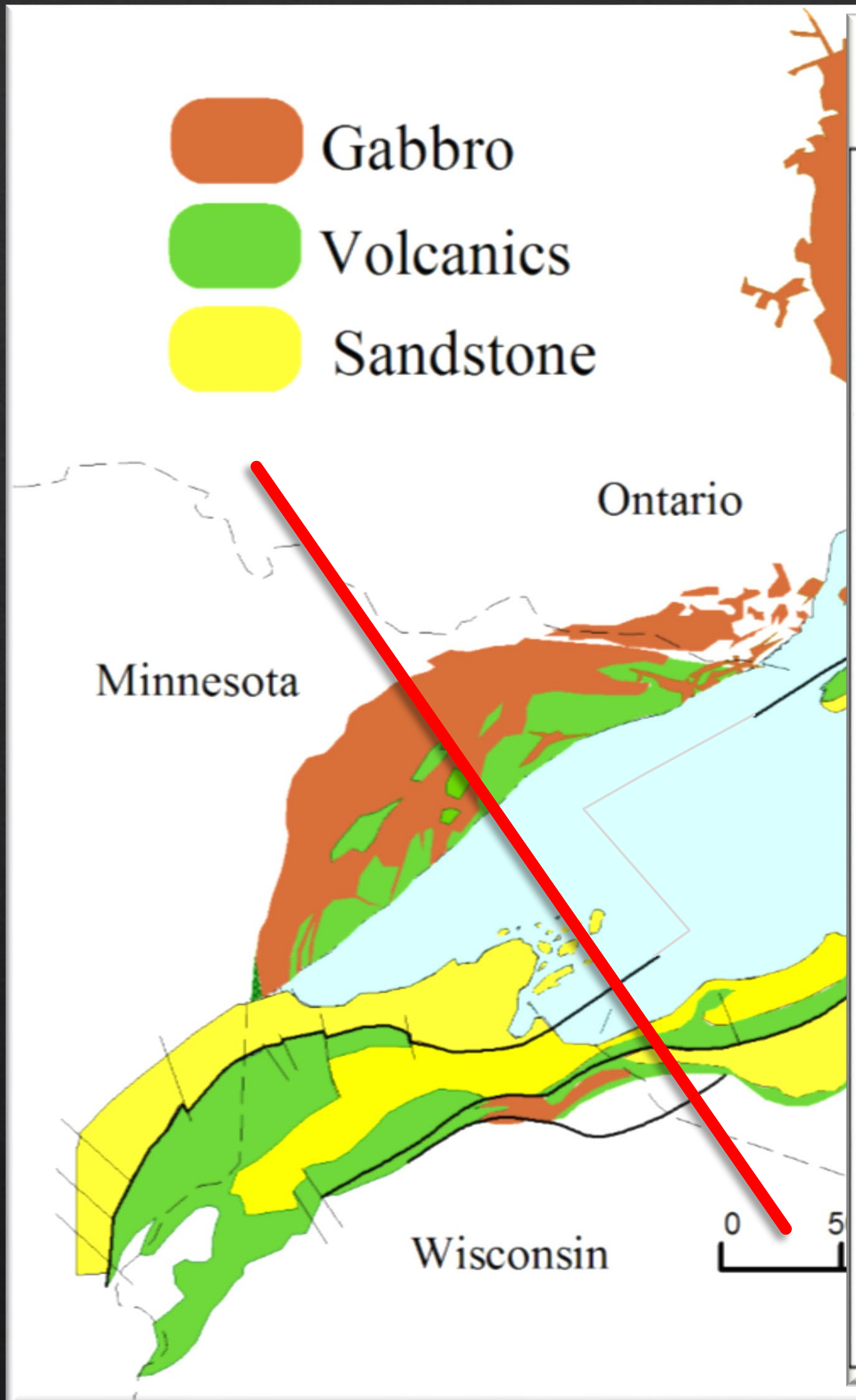


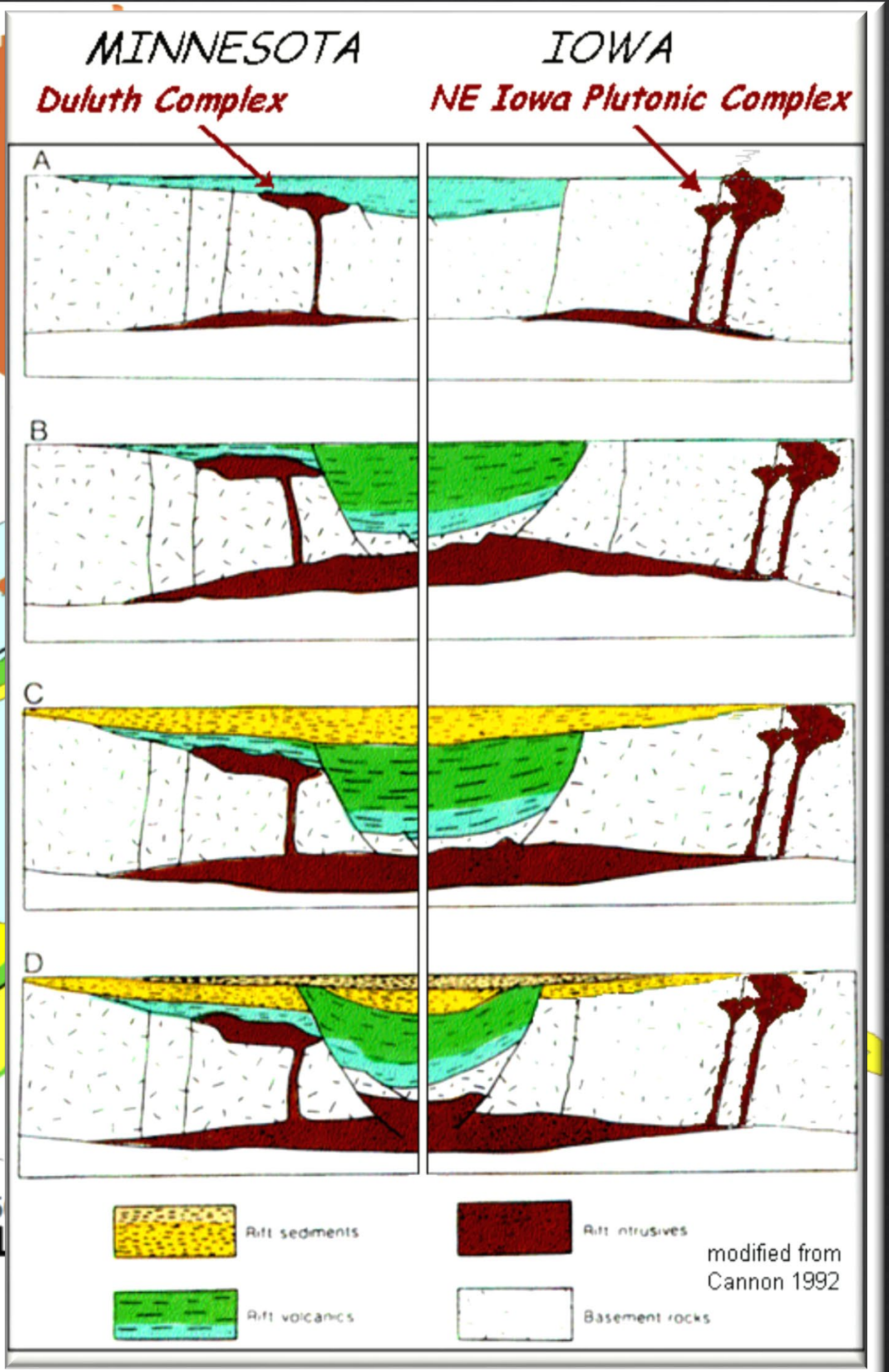


Shaded-relief map of the total magnetic intensity anomaly for the north-central United States. Data compiled by David L. Daniels and Stephen L. Snyder of the U.S. Geological Survey from various sources. Most of Minnesota was flown with a line spacing of 400 meters and an elevation (above land surface) of 150 meters, whereas much of Wisconsin was flown at line spacings of 400-800 meters and elevations between 150 to 305 meters. The remaining areas were generally flown at flight line spacings of 1600 meters or wider and at elevations of 305 meters or greater. Following gridding, all data were continued to a common elevation of 305 meters and merged. For more detailed descriptions of the original data sets the reader is referred to:

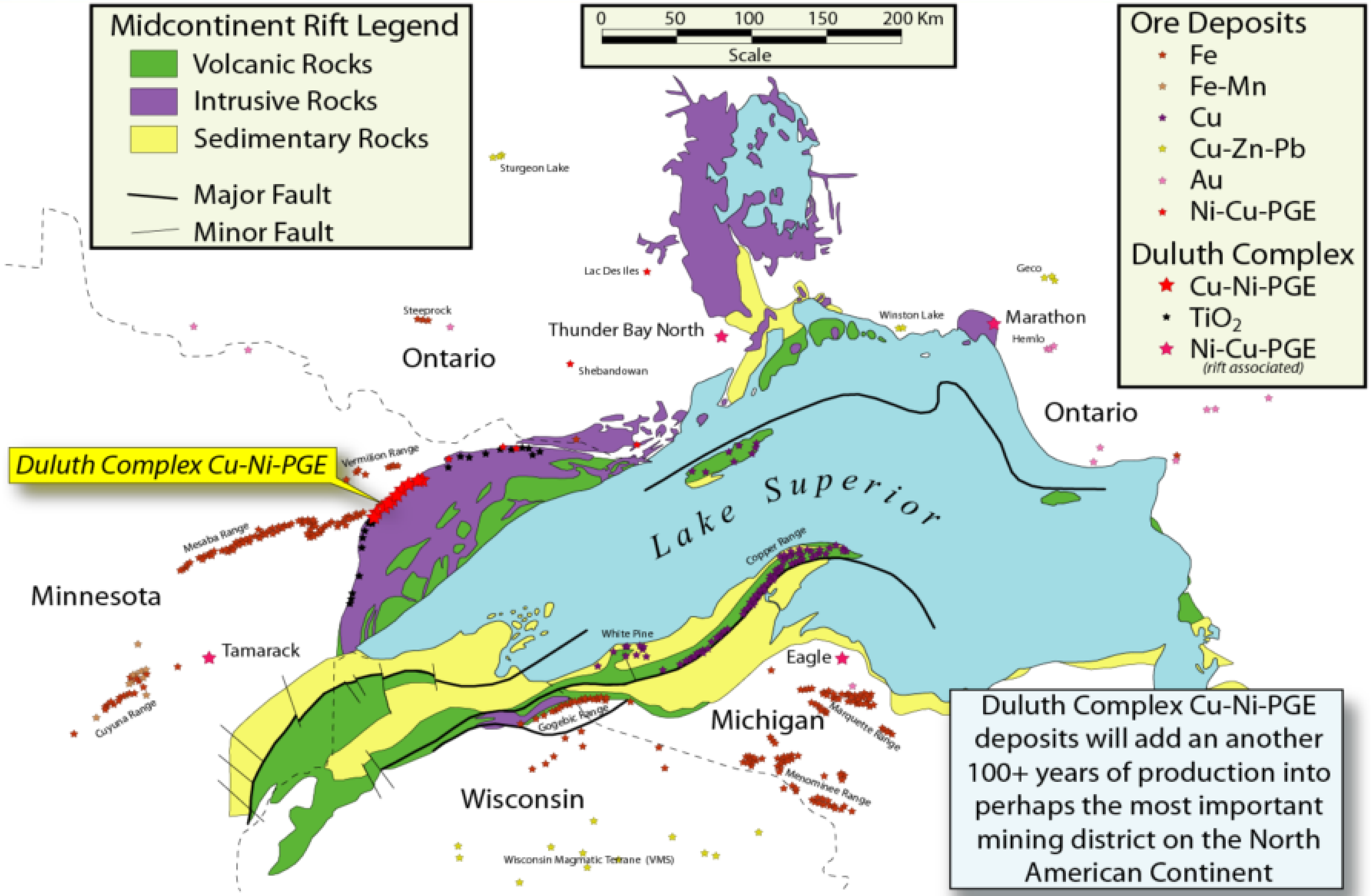
U.S. Geological Survey Crustal Imaging and Characterization Team Web Site.

Aeromagnetic data in Minnesota were acquired by the Minnesota Geological Survey (MGS), with support from the Legislative Commission on Minnesota Resources. Aeromagnetic data in Wisconsin were acquired with support from the Wisconsin Geological and Natural History Survey and the U. S. Geological Survey. Hillshade illumination is from the North with an inclination of 30 degrees.


Gabbro
Volcanics
Sandstone
Ontario
Minnesota
Wisconsin
0
5


MINNESOTA
Duluth Complex
IOWA
NE Iowa Plutonic Complex
A
B
C
D
Rift sediments
Rift intrusives
Rift volcanics
Basement rocks
modified from Cannon 1992

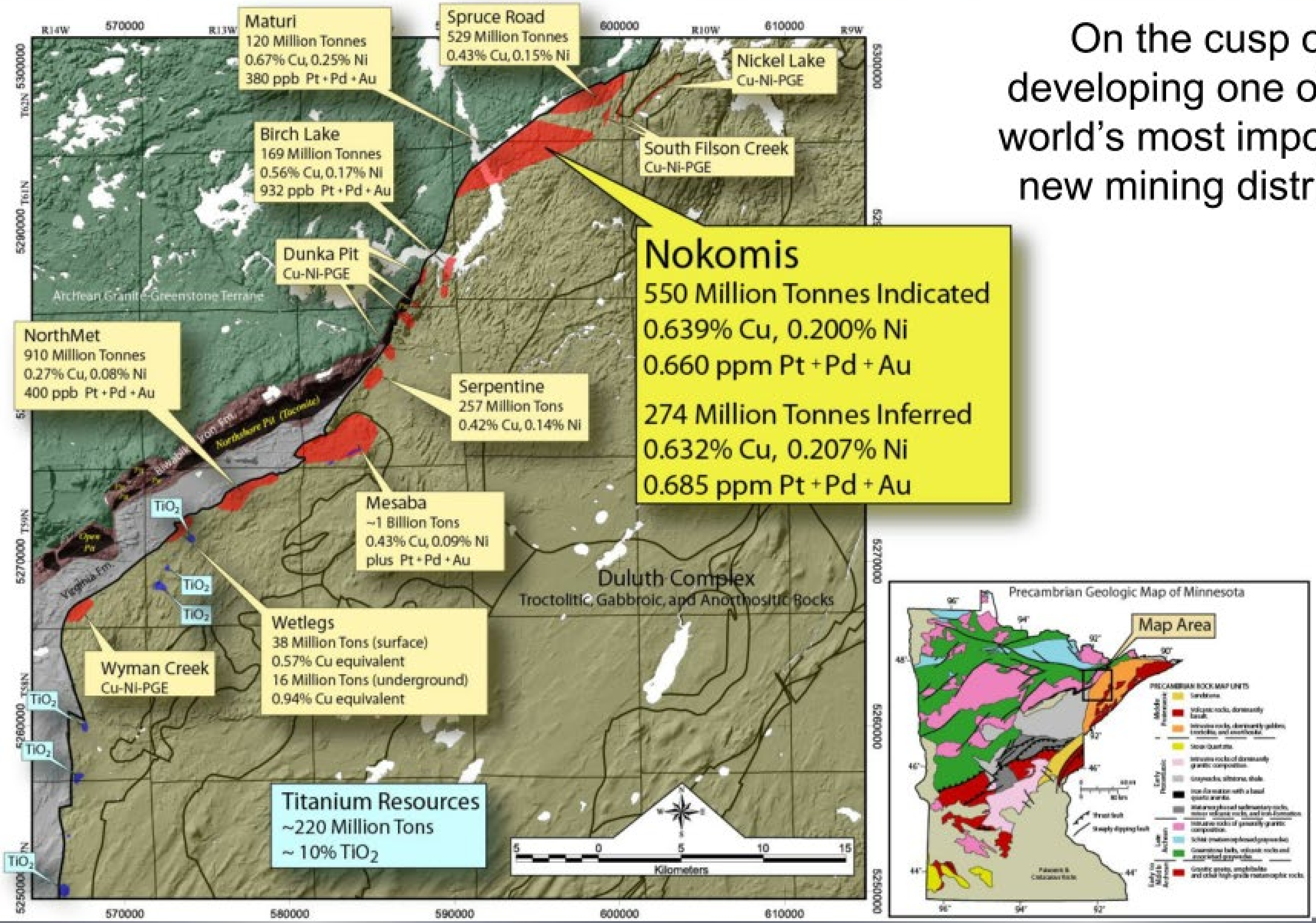
The Lake Superior Mining District



Duluth Complex Cu-Ni-PGE deposits will add an another 100+ years of production into perhaps the most important mining district on the North American Continent

Duluth Complex Mineral Resources

On the cusp of developing one of the world's most important new mining districts.



Updated TMM December 2012 Resource Estimate

Contained Metals in TMM NI 43-101Resource*

	Metal	Indicated	Inferred
Base	Copper $41 bill.	13.7 Billion lbs.	11.8 Billion lbs.
	Nickel $33 bill.	4.4 Billion lbs.	4.0 Billion lbs.
		$96.4 billion	
Precious	Platinum $8.6 bill.	5.6 Million ozs.	3.5 Million ozs.
	Palladium $8.8 bill.	12.6 Million ozs.	7.6 Million ozs.
	Gold $5.0 bill.	3.0 Million ozs.	1.7 Million ozs.
	TPM (Pt+Pd+Au)	21.2 Million ozs.	12.8 Million ozs.

*Reference: December 4, 2012 Company press release entitled "Duluth Metals Announces an Updated Mineral Resource Estimate Confirming Large Increases to Twin Metals Contained Metal, Grade and Indicated Tonnage"

** Note – These resource estimates include 100% of the identified material in each deposit, and include mineral resources acquired as a part of TMM's acquisition of Franconia Minerals Corporation in 2011. Franconia's principal assets are a 70% interest in the Birch Lake, 'old' Maturi and Spruce Road deposits in northeastern Minnesota through the Birch Lake Joint Venture. Franconia announced in November, 2010 its intention to increase its ownership at the Birch Lake Joint Venture to 82%; see Franconia's company profile at www.SEDAR.com for Technical Reports. TMM's ownership of the resource will be factored by these percentages where applicable.*

Duluth Complex Exploration

- Duluth Metals Ltd.
- PolyMet Mining
- Teck Cominco Ltd.
- Franconia Minerals Corp.
- Encampment Minerals Inc.

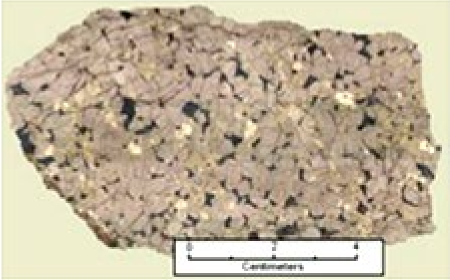
"The Duluth Complex is perhaps the world's largest untapped resource of (copper, nickel and platinum group metals) with multibillion tons of geologic resources estimated to be worth more than $1 trillion," stated a 2007 report by geologists at the Natural Resources Research Institute of the University of Minnesota Duluth.

Findings reported in recent months by Duluth Metals · · · indicate even the $1 trillion number may be too small.

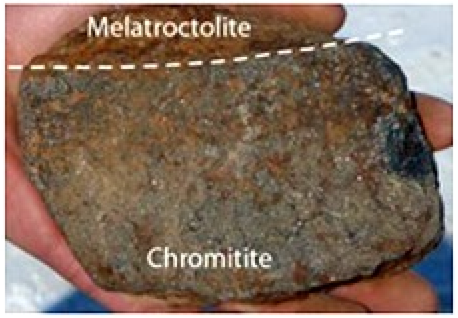
--Duluth News Tribune, June 20, 2010

Target Types

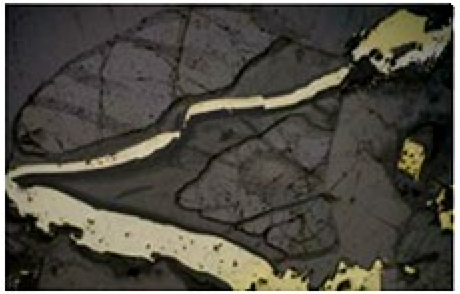
Ni-rich Massive Sulfide

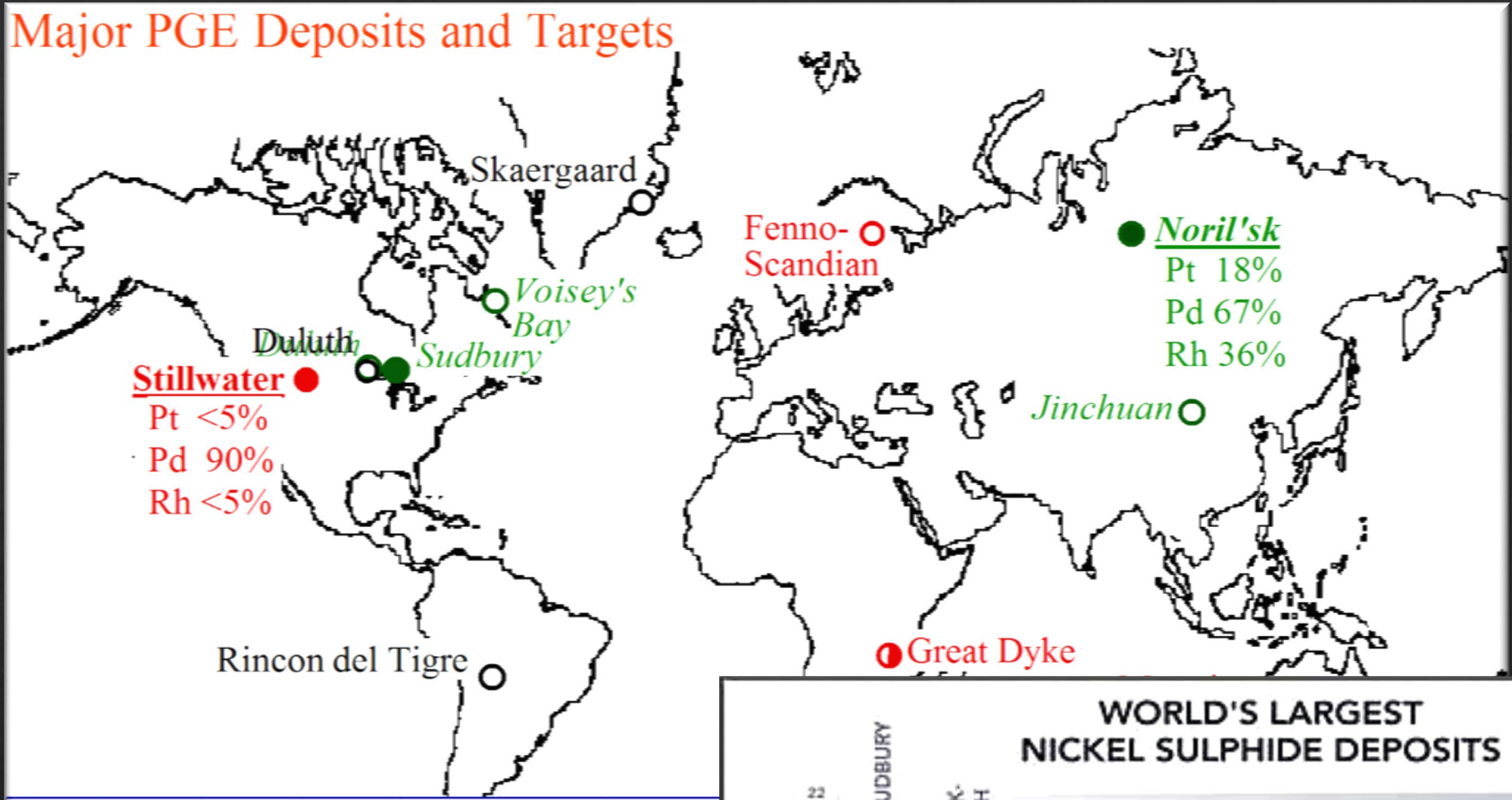


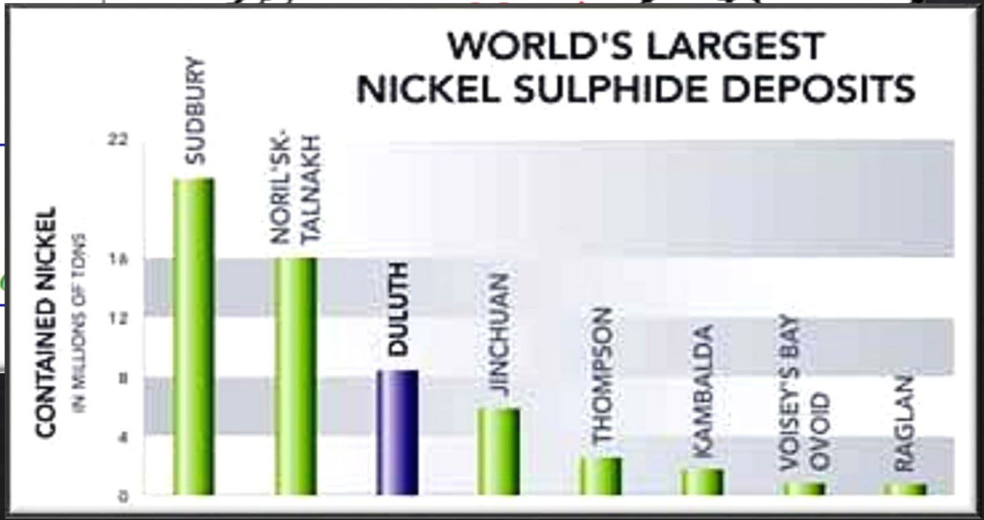
Pt-Pd Reefs w/ Cr



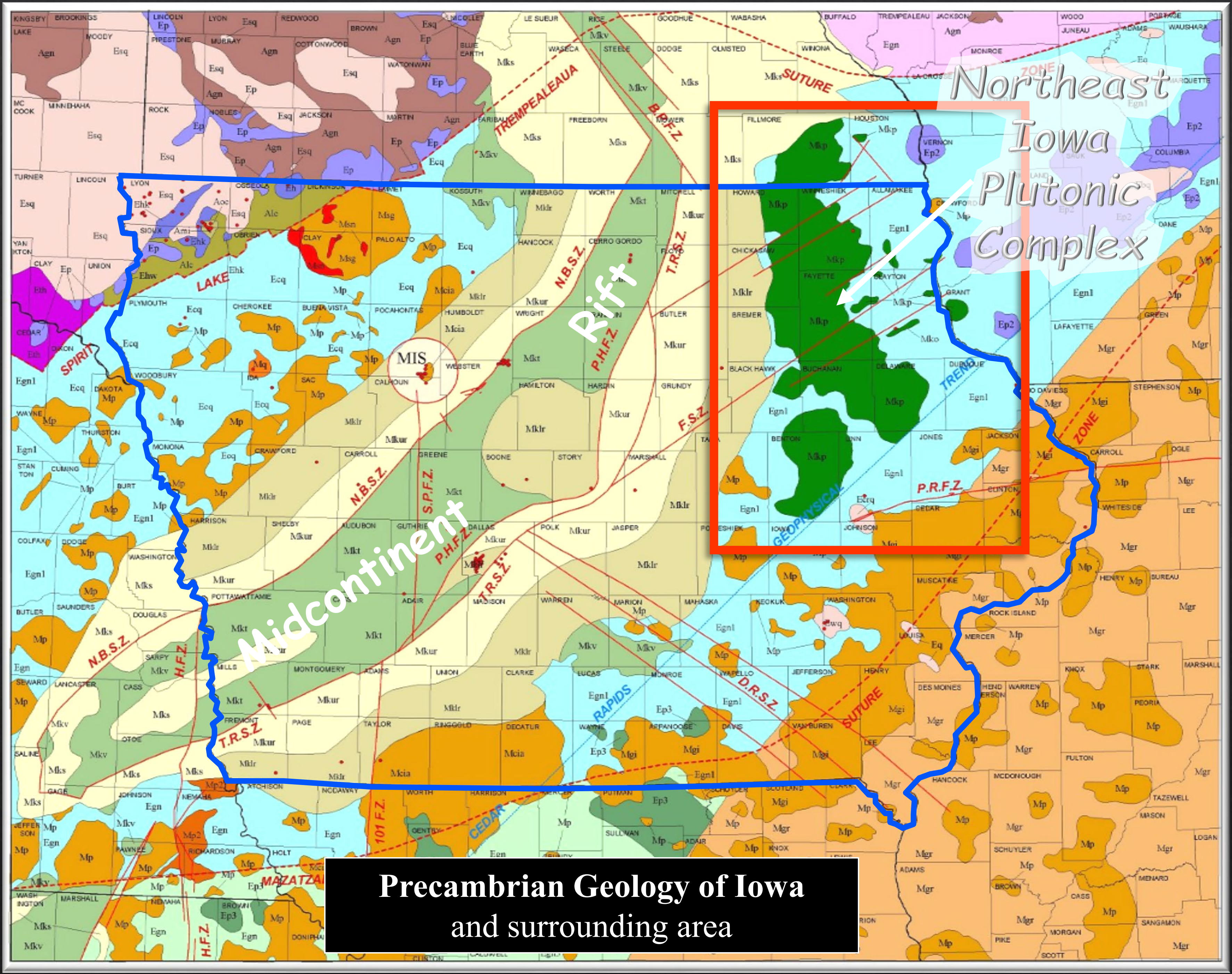
Disseminated Cu-Ni-PGE



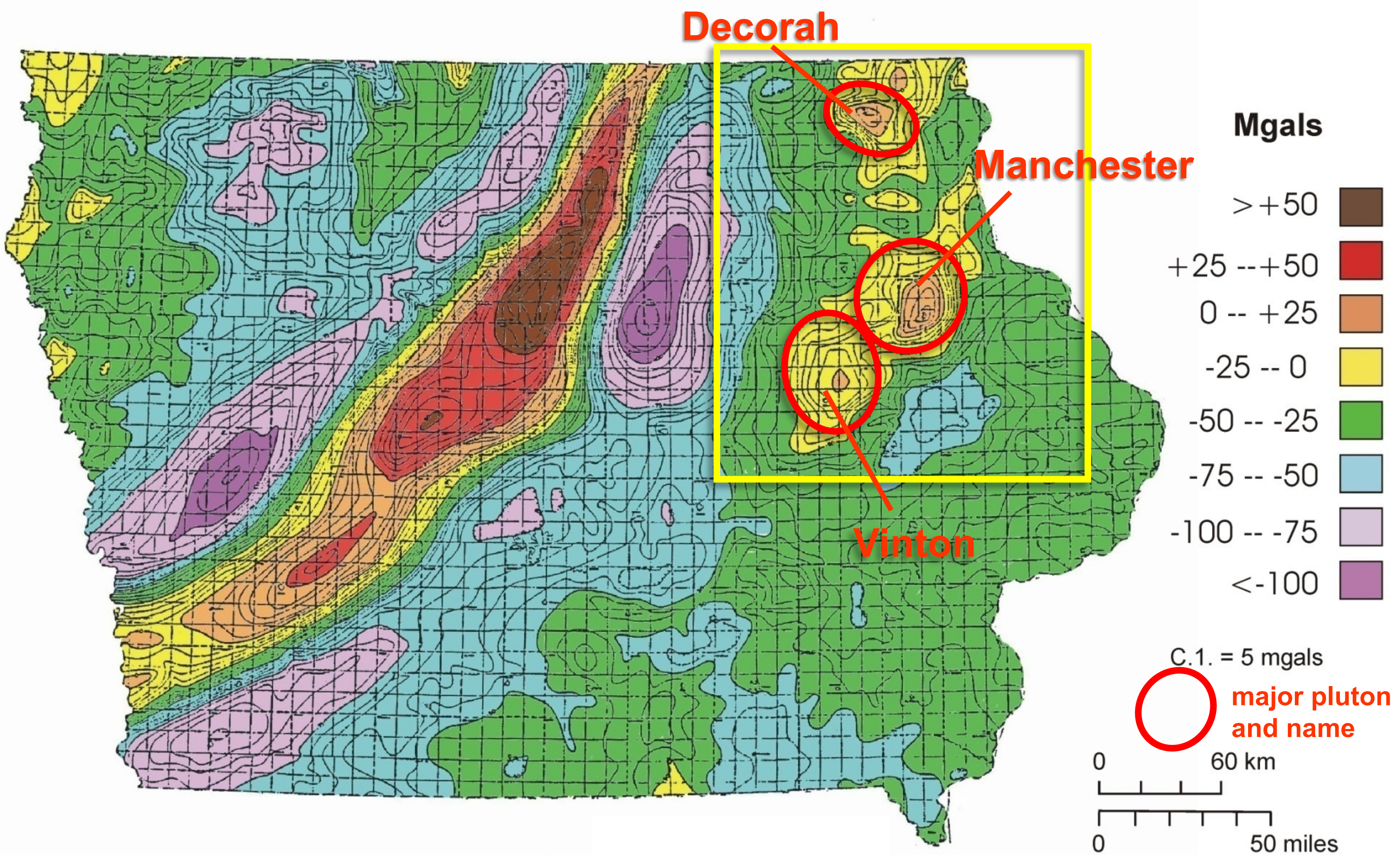

Major PGE Deposits and Targets
Skaergaard
Fenno-Scandian
Noril'sk
Pt 18%
Pd 67%
Rh 36%
Voisey's Bay
Duluth
Sudbury
Stillwater
Pt <5%
Pd 90%
Rh <5%
Jinchuan
Rincon del Tigre
Great Dyke
PGE-reefs in Ultramafic/Mafic Complexes
PGE-reefs in Tholeiitic Intrusions
PGE as by-product in Cu-Ni Sulfide


WORLD'S LARGEST NICKEL SULPHIDE DEPOSITS
CONTAINED NICKEL
IN MILLIONS OF TONS
SUDBURY
NORIL'SK-TALNAKH
DULUTH
JINCHUAN
THOMPSON
KAMBALDA
VOISEY'S BAY OVOID
RAGLAN

The Stillwater Mine (Montana)
Only Precious Metals Mine in the U.S. (owned by Noril'skNickel)


Northeast Iowa Plutonic Complex
Rift
Midcontinent
MIS
Precambrian Geology of Iowa
and surrounding area

BOUGUER GRAVITY ANOMALY MAP OF IOWA



modified from Anderson (1981)

BT-67 fixed wing turboprop aircraft that carried the gravity survey instrument

3,333 km = 2,071 mi of flight lines

400 m = ¼ mile flight line EW spacing
3.5 km = 2 ¼ mile flight line NS spacing

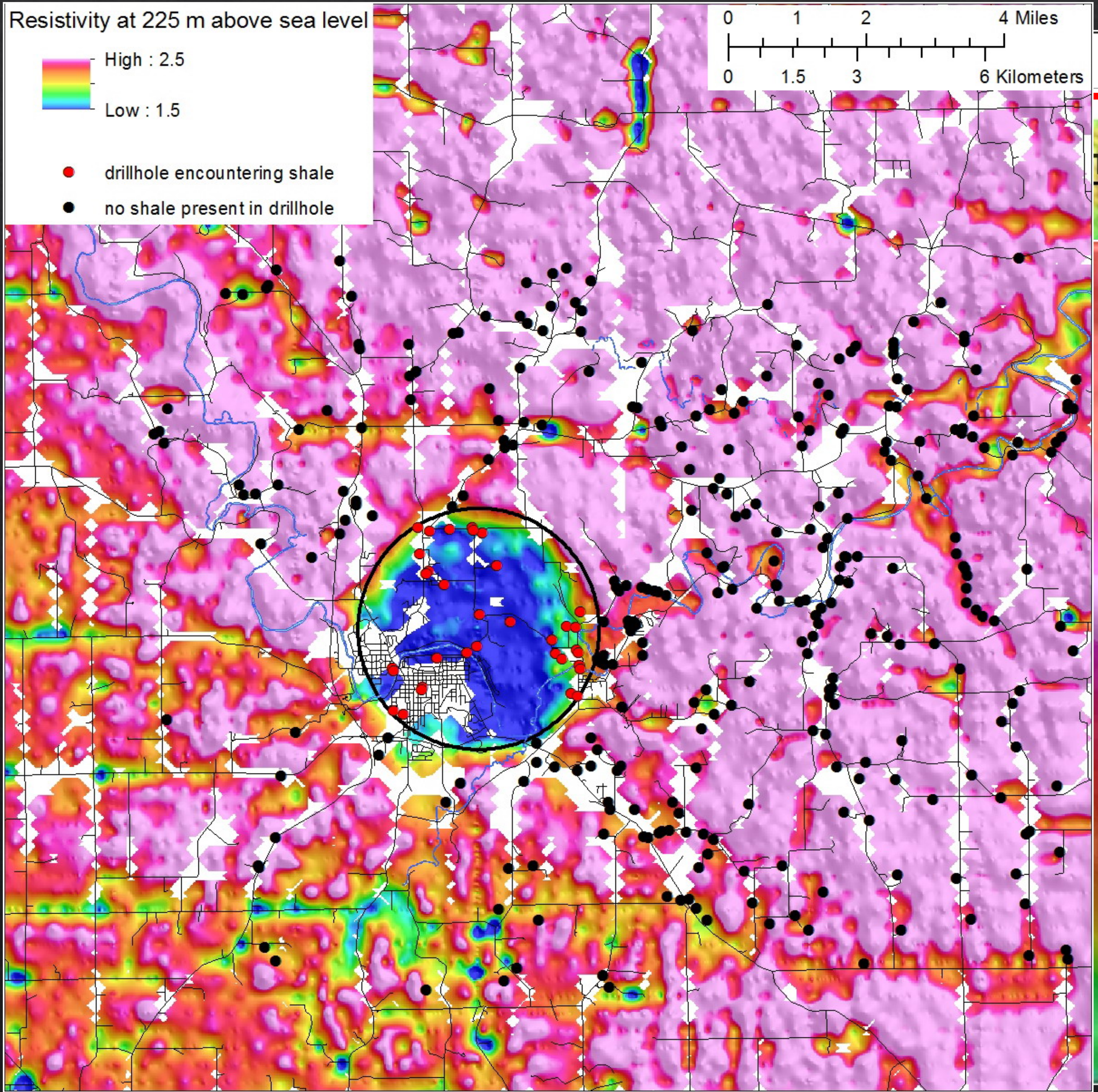
100 – 500 feet above the landscape

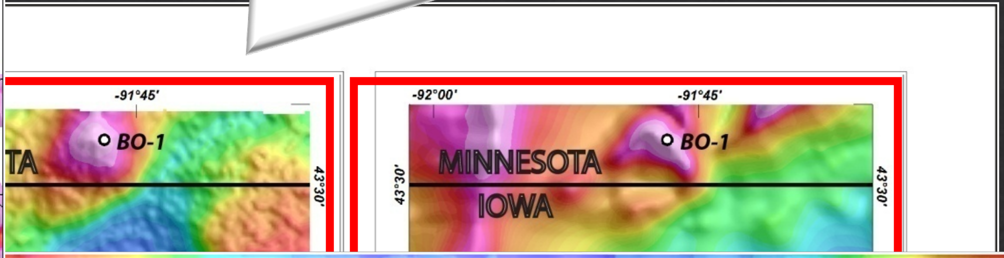
USGS
science for a changing world

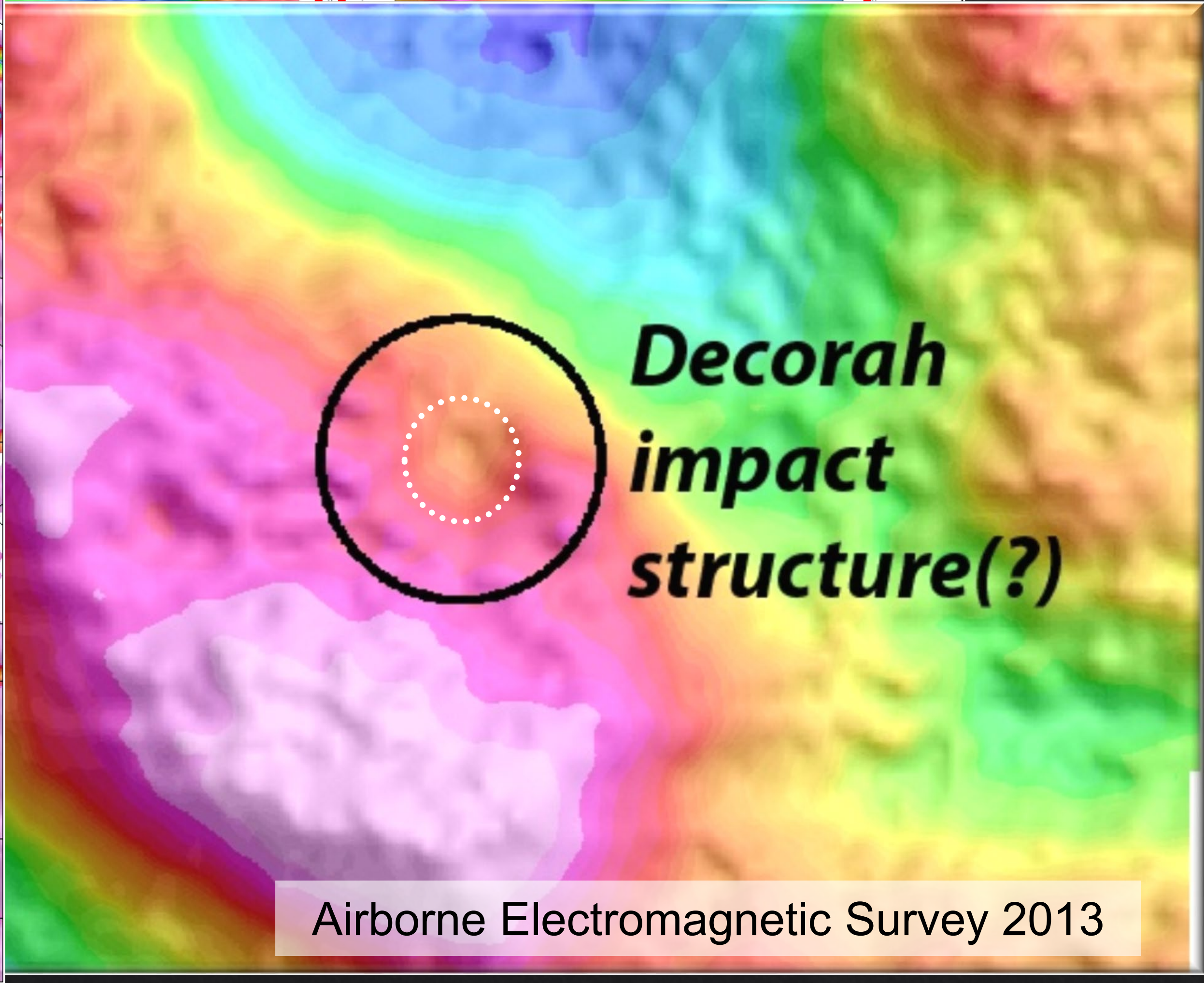
Agusta Westland AW119 Koala helicopter that carried the magnetometer and ectromagnetic surveys (see **VTEM** detector suspended below helicopter)

Versatile **T**ime **D**omain **E**lectro**m**agnetic Surveying

Preliminary Data from USGS Airborne Gravity Survey







Manufacturing Depends on Minerals

- Manufactures use minerals to create the high-tech devices that connect us to the world. TVs require 35 different minerals and computer chips can require up to 60 minerals and elements.

- From the mirrors and paint to the body frame and engine, minerals are integral to every vehicle on the road. Gold, platinum and aluminum are just a few of the minerals used by auto manufacturers.

- Advanced energy technologies such as wind turbines, electric vehicles and solar panels depend on minerals including rare earths, copper and zinc.

2019 Rank State Value U.S. total in order of value

1 Nevada	**$11,200,000,000**	14.58	Gold, copper, silver, lime, sand and gravel (construction).
2 Arizona	**8,050,000,000**	10.52	Copper, molybdenum conc., sand and gravel (construction), cement (portland), silver.
3 Minnesota	**4,500,000,000**	5.88	Iron ore (usable shipped), sand and gravel (construction and industrial), stone (crushed and dimension).
4 Florida	**3,640,000,000**	4.76	Phosphate rock, stone (crushed), cement (portland), sand and gravel (construction), zirconium concentrates.
5 California	**3,580,000,000**	4.68	Sand and gravel (construction), boron minerals, cement (portland), gold, stone (crushed).
28 Iowa	**731,000,000**	0.96	Stone (crushed), cement (portland), sand and gravel (construction and industrial), lime

Total

U.S. $76,500,000,000.00

Minerals Make Economic Growth

Jobs and Wages

- A job in U.S. metals mining carries an average salary of approximately $85,500 a year—74 percent higher than the combined average of all private sector jobsi.

- More than 1.3 million U.S. jobs are supported through minerals mining — 433,000 Americans are directly employed and more than 872,000 are indirectly employed.

- For every job in metals mining, an estimated 2.9 additional jobs are generated, and for every nonmetals mining job, an additional 1.8 jobs are created.

BMC

Martin Marietta Materials

IOWA LIMESTONE PRODUCERS ASSOCIATION

Your limestone resource since 1945!

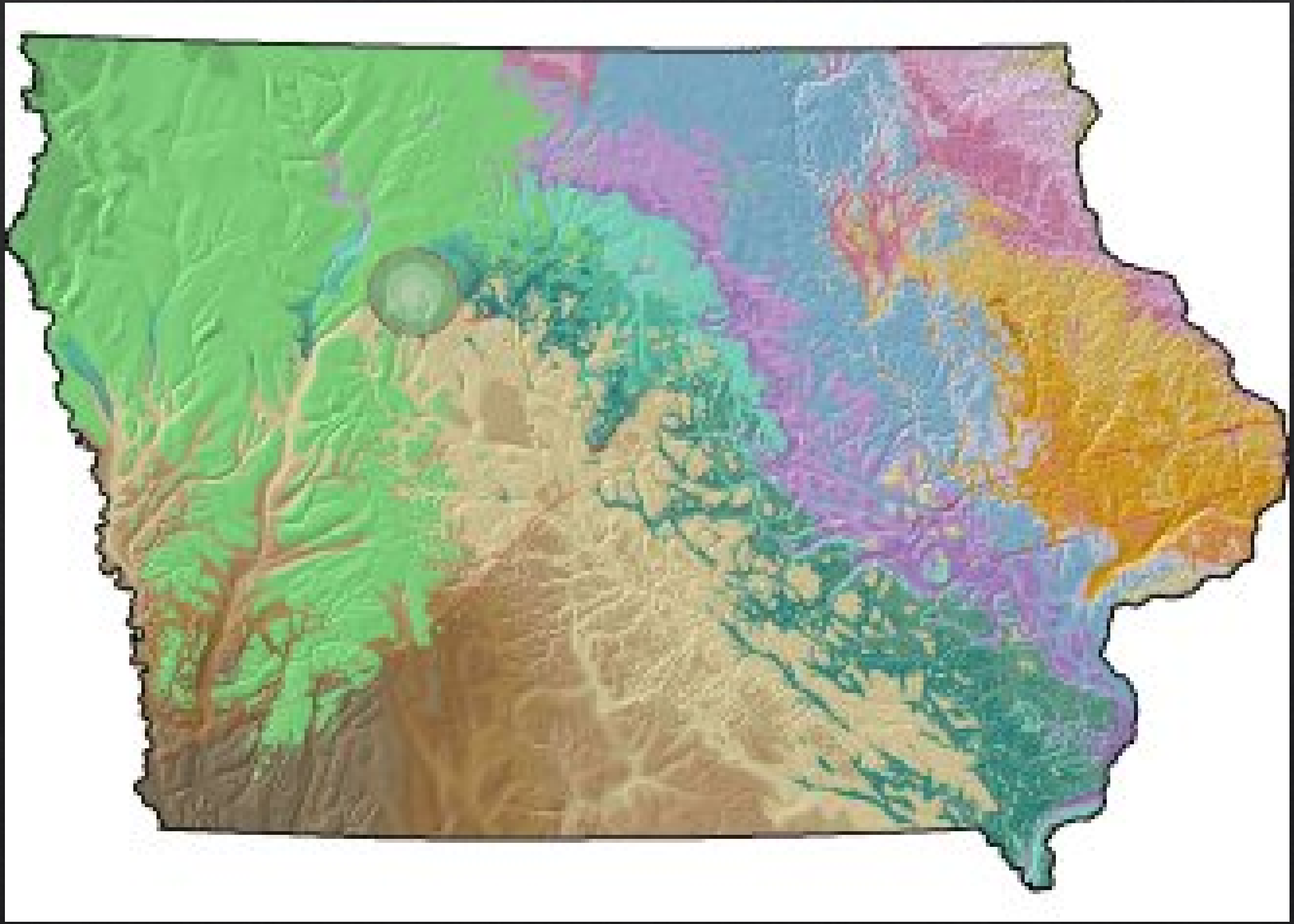
www.limestone.org

RIVER PRODUCTS COMPANY
IOWA CITY, IOWA

Wendling Quarries Inc.

Iowa’s Minerals

- Galena
  - Lead
  - Zinc
- Gypsum
- Silica sand
- Iron



Iowa - Lead and Zinc

- Near Dubuque, Iowa
- Start approx. 1650
- Peak 1830 to 1860
- End 1910

Iowa – Iron ore

- Waukon, Allamakee County
- Iron Hill deposit
- First mined in 1899
- Missouri Iron Company of St. Louis operated a plant in Iowa until 1918.

Iowa – Clay

- In 1900 there were 381 clay companies operating in 89 of Iowa's counties!
- Shale bedrock, river alluvium, glacial sediment
- Produced brick and tile
- Today only 3 companies mine clay for bricks in Dallas and Woodbury counties

Iowa – Cement

- Burnt lime via kiln fired limestone.
  - Calcining to produce quicklime or calcium oxide
  - $CaCO_3$ + Heat → CaO + CO_2(g)
- Silurian Age Dolostone
  - Hopkinton Formation
    - Farmers Creek Member
    - Marcus Member
- Jackson and Cedar Counties

Iowa - Portland Cement

- Hardens underwater
- Put Kiln burning out of business
- Four plants continue to operate in Cerro Grodo, Polk, and Scott counties.
- Accounts for approx. 40% of mineral production today in Iowa.

Iowa - Stone

- 19th century construction
- Primary production centers include Cedar, Jones, Des Moines, Marshall, Lee, Madison and Jackson counties
- In 1982, crushed stone surpassed Portland Cement as Iowa's leading mineral commodity
- There are nearly 500 registered quarries in Iowa today

Iowa – Gypsum

- Fort Dodge, Iowa 1850
- Two million tons per year at a value of $12 million
- Products
  - Wall board
  - Portland cement

Iowa – Sand and Gravel

- Important resource for Iowa's roads and construction.
- In Iowa's river valleys past and present…
- Approx. 16 million tons per year are mined per year at a value of approx. $60 million.

The End