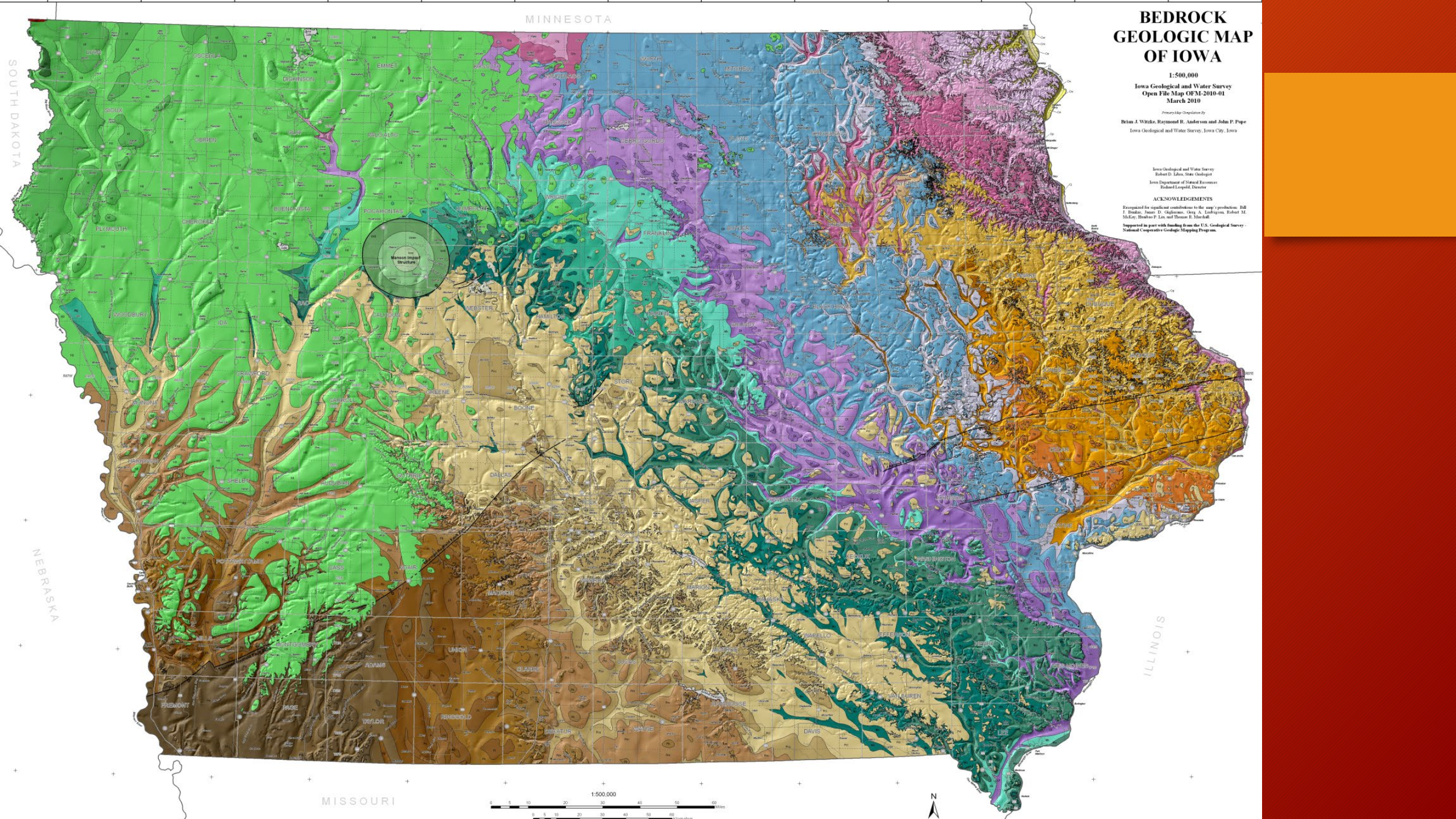


Iowa's Bedrock & Fossils

Part 1

Geological Resources of Iowa
University of Northern Iowa &
The Iowa Limestone Producers Association



BEDROCK GEOLOGIC MAP OF IOWA

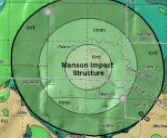
1:500,000
Iowa Geological and Water Survey
Open File Map OFM-2010-01
March 2010

Primary Map Compilation by
Brian J. Wilke, Raymond R. Anderson and John P. Pope
Iowa Geological and Water Survey, Iowa City, Iowa

Iowa Geological and Water Survey
Robert D. Liles, State Geologist
Iowa Department of Natural Resources
Richard Leopold, Director

ACKNOWLEDGEMENTS

Recognized for significant contributions to the map's production: Bill J. Enslin, Susan D. Chapman, Greg A. Lindgren, Robert M. McKay, Brandon P. Lee, and Thomas E. Marshall.
Supported in part with funding from the U.S. Geological Survey - National Cooperative Geologic Mapping Program.



MISSOURI

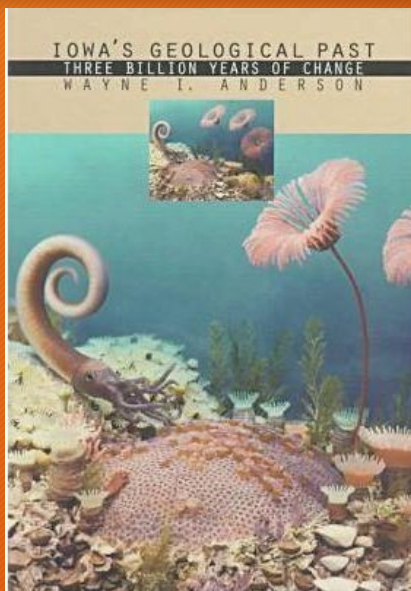
MINNESOTA

SOUTH DAKOTA

NEBRASKA

ILLINOIS

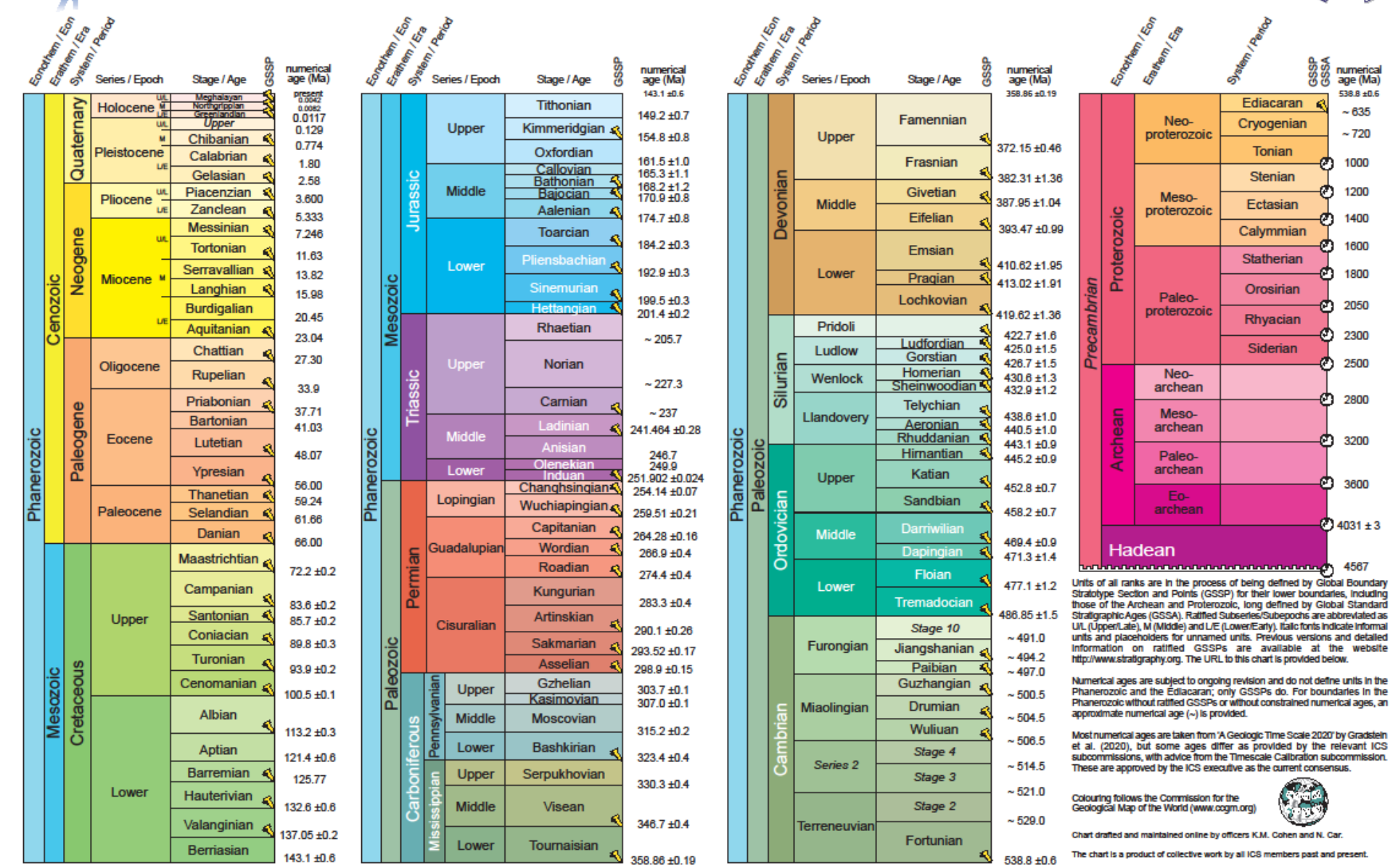
Geologic Time



Wayne Anderson
 Jim Walters
 Ray Anderson
 Brian Glenister

INTERNATIONAL CHRONOSTRATIGRAPHIC CHART v 2024/12

www.stratigraphy.org International Commission on Stratigraphy



Units of all ranks are in the process of being defined by Global Boundary Stratotype Section and Points (GSSP) for their lower boundaries, including those of the Archean and Proterozoic, long defined by Global Standard Stratigraphic Ages (GSSA). Ratified Subseries/Subepochs are abbreviated as UL (Upper/Late), M (Middle) and LE (Lower/Early). Italic fonts indicate informal units and placeholders for unnamed units. Previous versions and detailed information on ratified GSSPs are available at the website <http://www.stratigraphy.org>. The URL to this chart is provided below.

Numerical ages are subject to ongoing revision and do not define units in the Phanerozoic and the Ediacaran; only GSSPs do. For boundaries in the Phanerozoic without ratified GSSPs or without constrained numerical ages, an approximate numerical age (-) is provided.

Most numerical ages are taken from 'A Geologic Time Scale 2020' by Gradstein et al. (2020), but some ages differ as provided by the relevant ICS subcommissions, with advice from the Timescale Calibration subcommission. These are approved by the ICS executive as the current consensus.

Colouring follows the Commission for the Geological Map of the World (www.cgm.org)

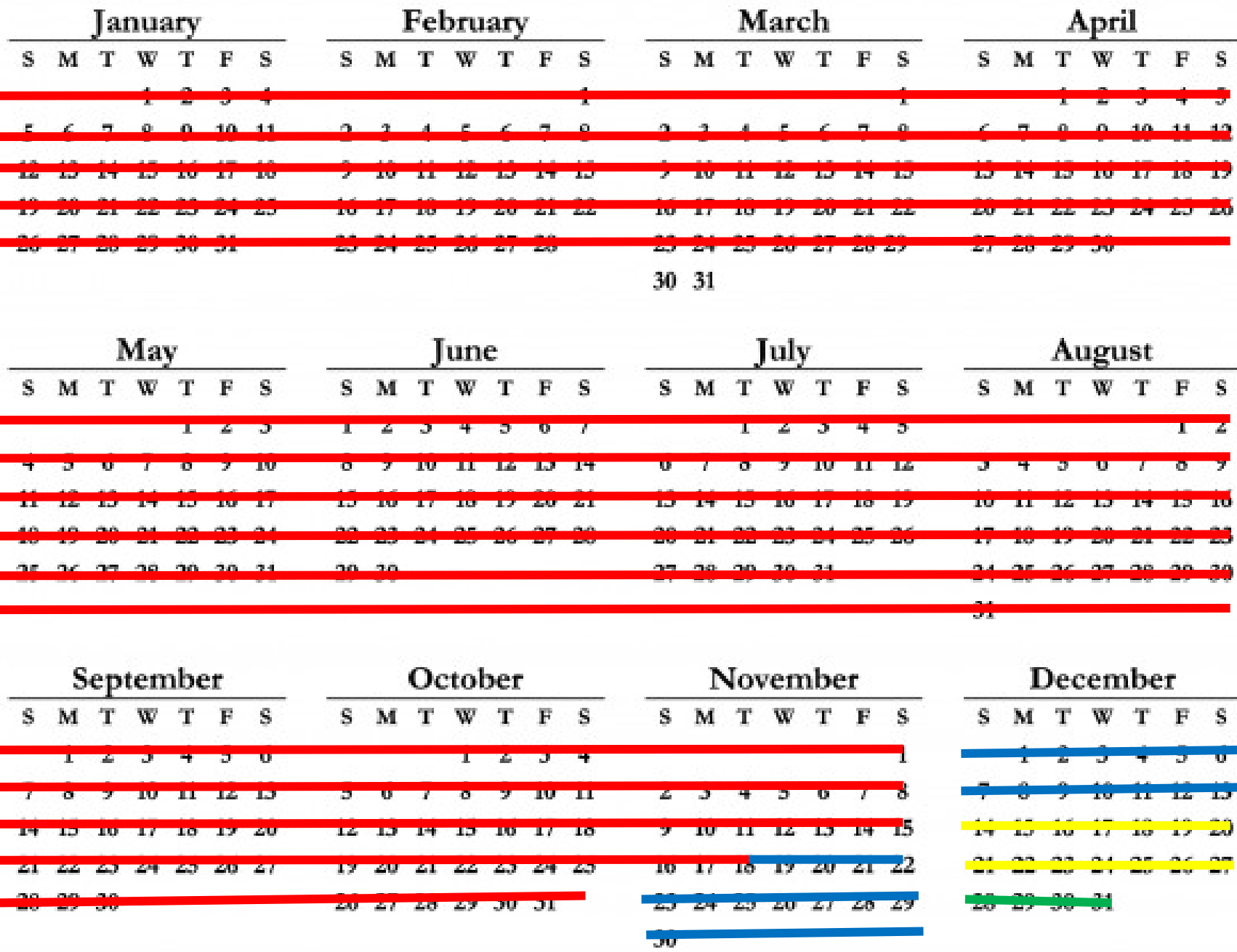
Chart drafted and maintained online by officers K.M. Cohen and N. Car.

The chart is a product of collective work by all ICS members past and present.

(c) International Commission on Stratigraphy, December 2024

URL: <http://www.stratigraphy.org/ICSchart/ChronostratChart2024-12.pdf>

To cite: Cohen, K.M., Finney, S.C., Gibbard, P.L. & Fan, J.-X. (2013); updated) The ICS International Chronostratigraphic Chart. Episodes 36: 199-204



- Precambrian
 - 4 Billion years —————
- Paleozoic
 - 545-245 Ma —————
- Mesozoic
 - 245-65 Ma —————
- Cenozoic
 - 65-2Ma —————
- Pleistocene
 - 2Ma-11,200

3 hours

The Holocene

- About the past 11,200 years
 - North America was populated
 - Civilizations have come and gone
 - Volcanoes have erupted
 - Glaciers have melted
 - Atmospheric Carbon dioxide has skyrocketed
 - The Cubs won 2 World Series...

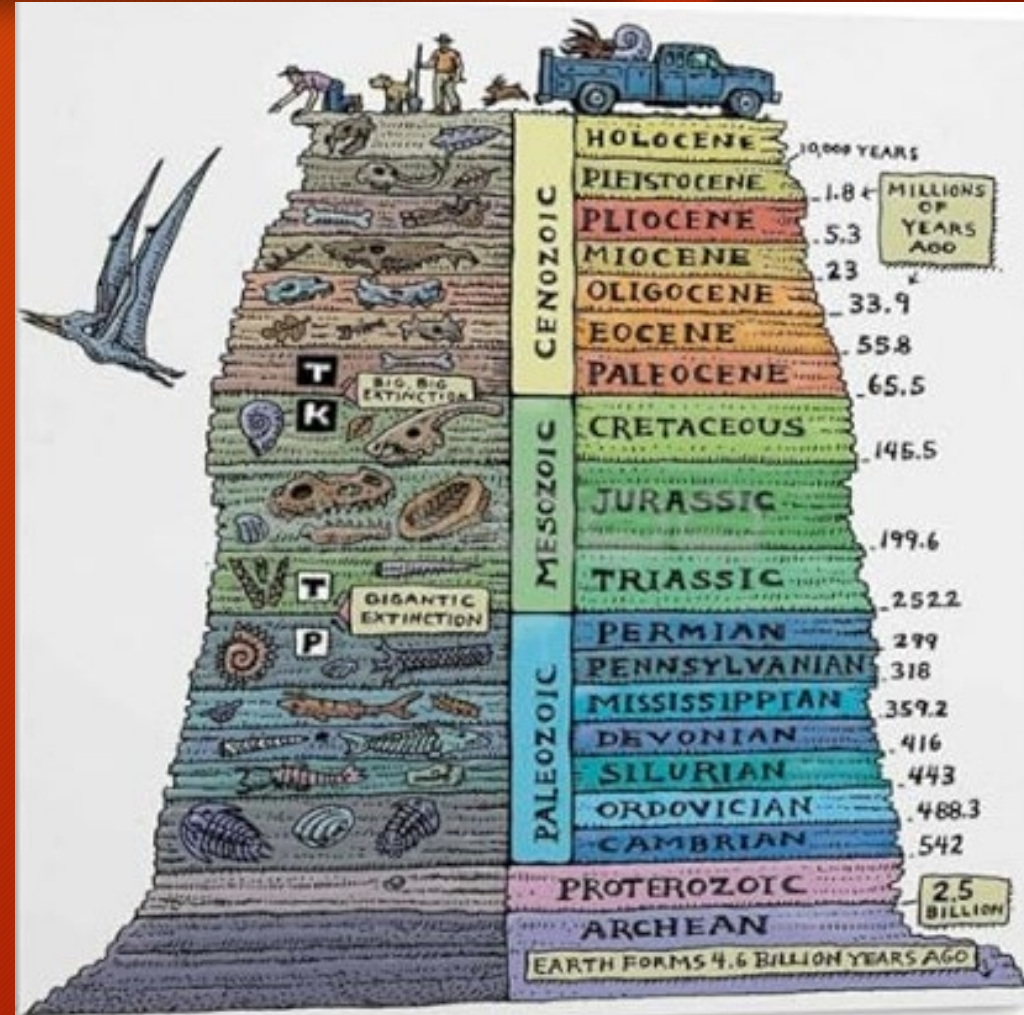
About 1.1
minutes

Major Unconformities in Iowa

- Base of Cambrian
- Within Ordovician
- Base of Devonian
- Between the Mississippian and Pennsylvanian
- Between the Jurassic and Cretaceous
- Iowa does not have any exposed rocks dating to the Permian or Triassic

Origin of Geologic Time Names

- Use of tribal names
 - Ordovician - Ordovices (historic Welsh tribe that was the last to submit to the Romans).
 - Silurian - Silures (ancient Wales tribe)
- Geographic localities
 - Cambrian - Cambria (Roman name for Wales)
 - Devonian - Region of Devonshire England



BIG IDEA *The Earth is 4.6 billion years old*



Clair Patterson
Mitchellville, Iowa

Some consider him the
most influential geologist
of the century!

What do we use to interpret Iowa Geologic History?



Precambrian Life

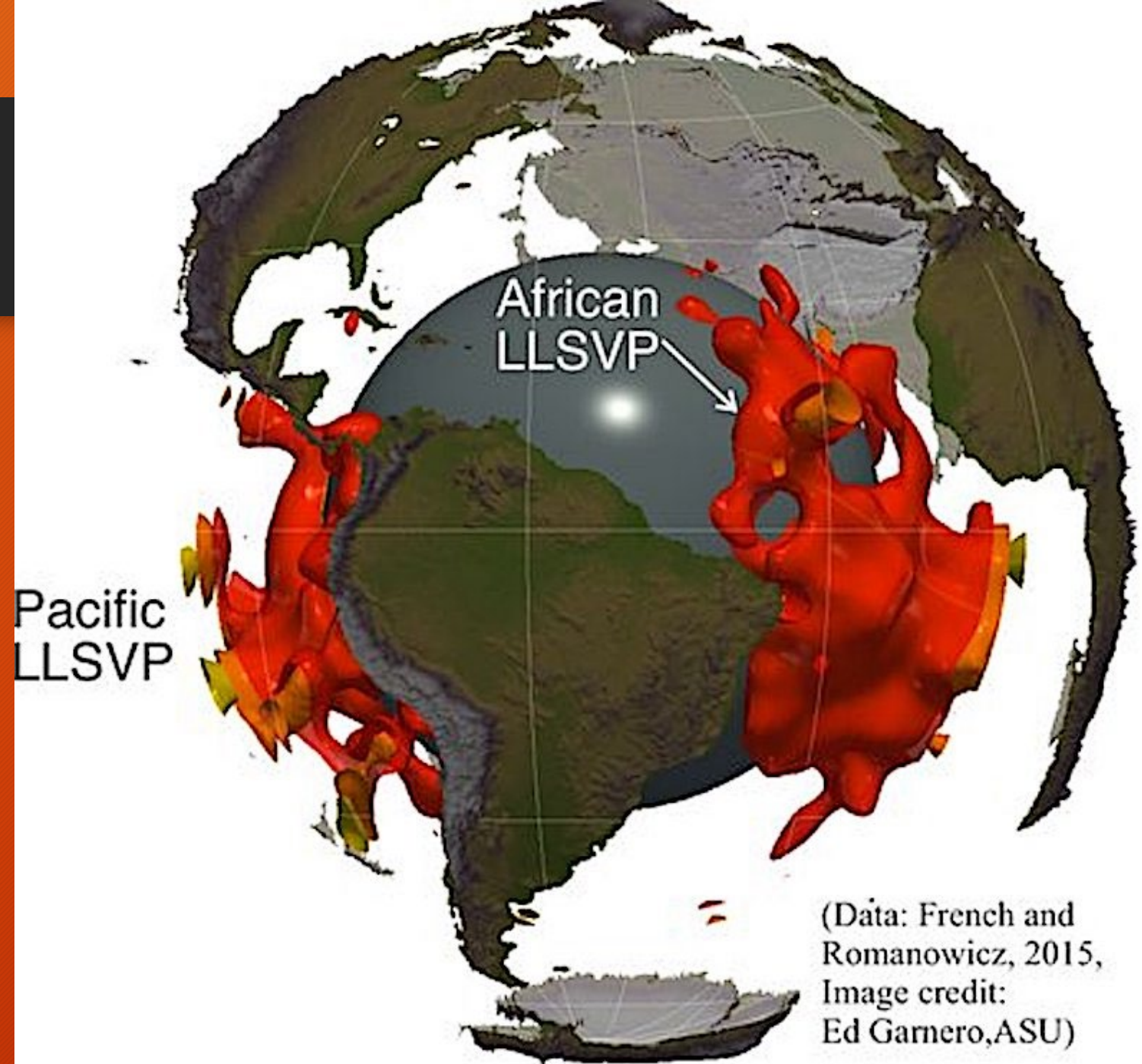


Theia



Large low-velocity provinces (LLSVP)

- **Lunar Rock Composition** - Earth's crust and Moon have similar chemical composition.
- **Isotopic ratios** - Analysis of potassium & iron isotopes, show slight differences between deep-mantle materials and the rest of Earth. This may be signatures of material that predates the collision, such as Theia's mantle.





ARTEMIS II

First Crewed Test Flight to the Moon Since Apollo

- 1 LAUNCH**
Astronauts lift off from pad 39B at Kennedy Space Center.
- 2 JETTISON SOLID ROCKET BOOSTERS, FAIRINGS, AND LAUNCH ABORT SYSTEM**
- 3 CORE STAGE MAIN ENGINE CUT OFF**
With separation.
- 4 PERIGEE RAISE MANEUVER**
- 5 APOGEE RAISE BURN TO HIGH EARTH ORBIT**
Begin 23.5 hour checkout of spacecraft.
- 6 ORION SEPARATION FROM INTERIM CRYOGENIC PROPULSION STAGE (ICPS) FOLLOWED BY PROX OPS DEMO**
Plus manual handling qualities assessment for up to 2 hours.
- 7 ORION UPPER STAGE SEPARATION (USS) BURN**
Begins high Earth orbit checkout. Life support, exercise, and habitation equipment evaluations.
- 8 PERIGEE RAISE BURN**
- 9 TRANS-LUNAR INJECTION (TLI) BY ORION'S MAIN ENGINE**
Lunar free return trajectory initiated with European service module.
- 10 OUTBOUND TRANSIT TO MOON**
Outbound Trajectory Correction (OTC) burns as necessary for Lunar free return trajectory; travel time approximately 4 days.
- 11 LUNAR FLYBY**
6,479 miles / 10,427 km (mean) lunar farside altitude.
- 12 TRANS-EARTH RETURN**
Return Trajectory Correction (RTC) burns as necessary to aim for Earth's atmosphere; travel time approximately 4 days.
- 13 CREW MODULE SEPARATION FROM SERVICE MODULE**
- 14 ENTRY INTERFACE (EI)**
Enter Earth's atmosphere.
- 15 SPLASHDOWN**
Ship recovers astronauts and capsule.

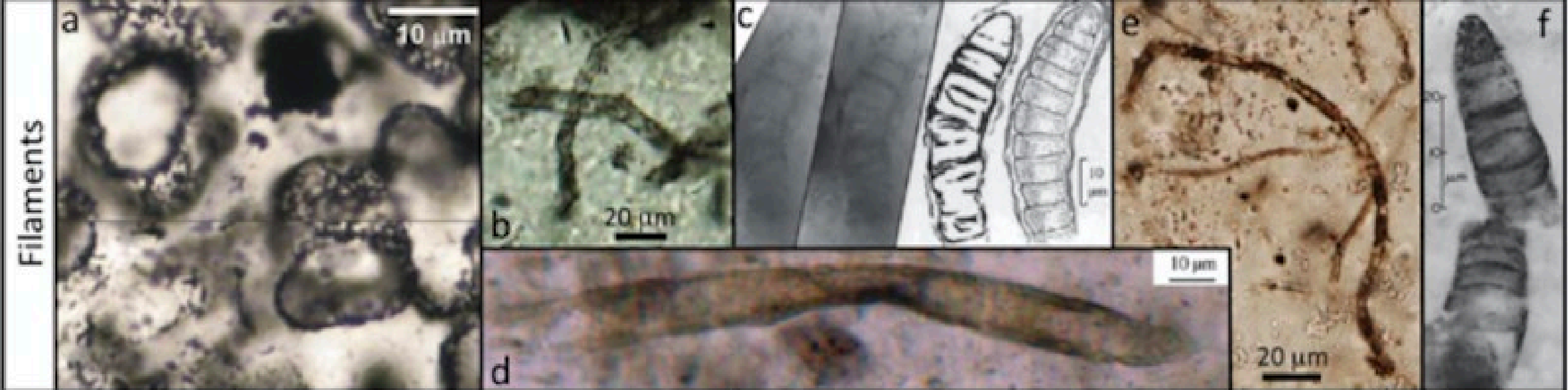
PROXIMITY OPERATIONS DEMONSTRATION SEQUENCE	
1	9
2	10
3	11
4	12
5	13
6	14
7	15
8	16
	17



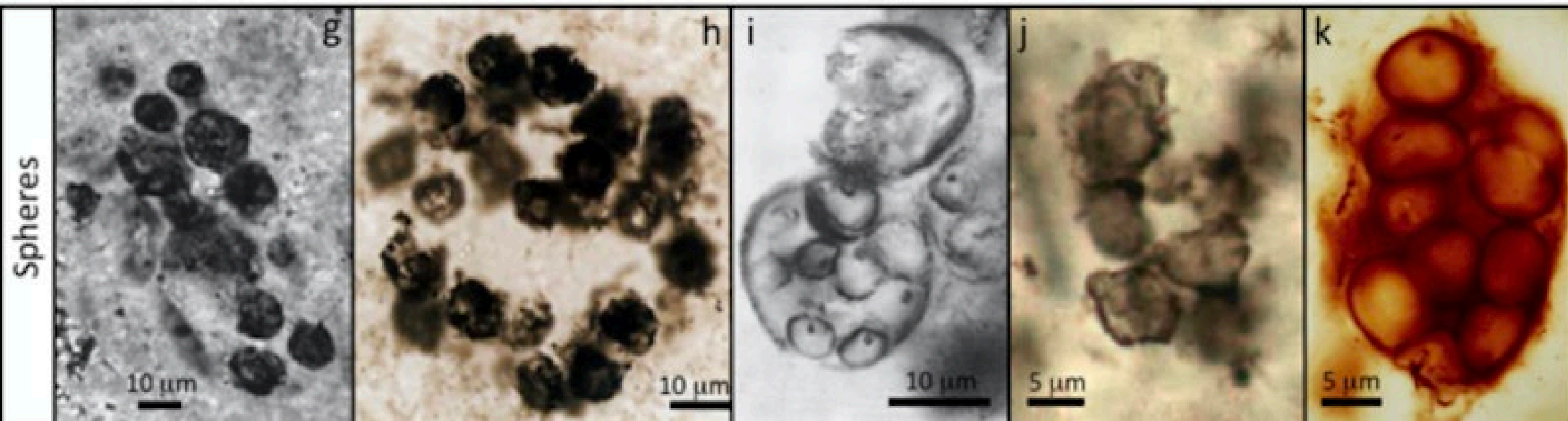




Great Oxygenation Event
~2.4 - 2.0 Ga - 2 to 20% O₂



TIME



Stromatolites - cyanobacteria trapping sediment and precipitating calcium carbonate



Water and Life on Earth Summary

Earth became a “water planet”

- It formed with (and received) large amounts of water early on
- It cooled enough to keep water in liquid form
- Gravity and atmospheric conditions allowed oceans to persist
- Unlike many other planets, Earth sits in the right temperature range and has enough mass to hold onto both water and an atmosphere—key reasons it still has oceans today.

Precambrian → Cambrian transition:

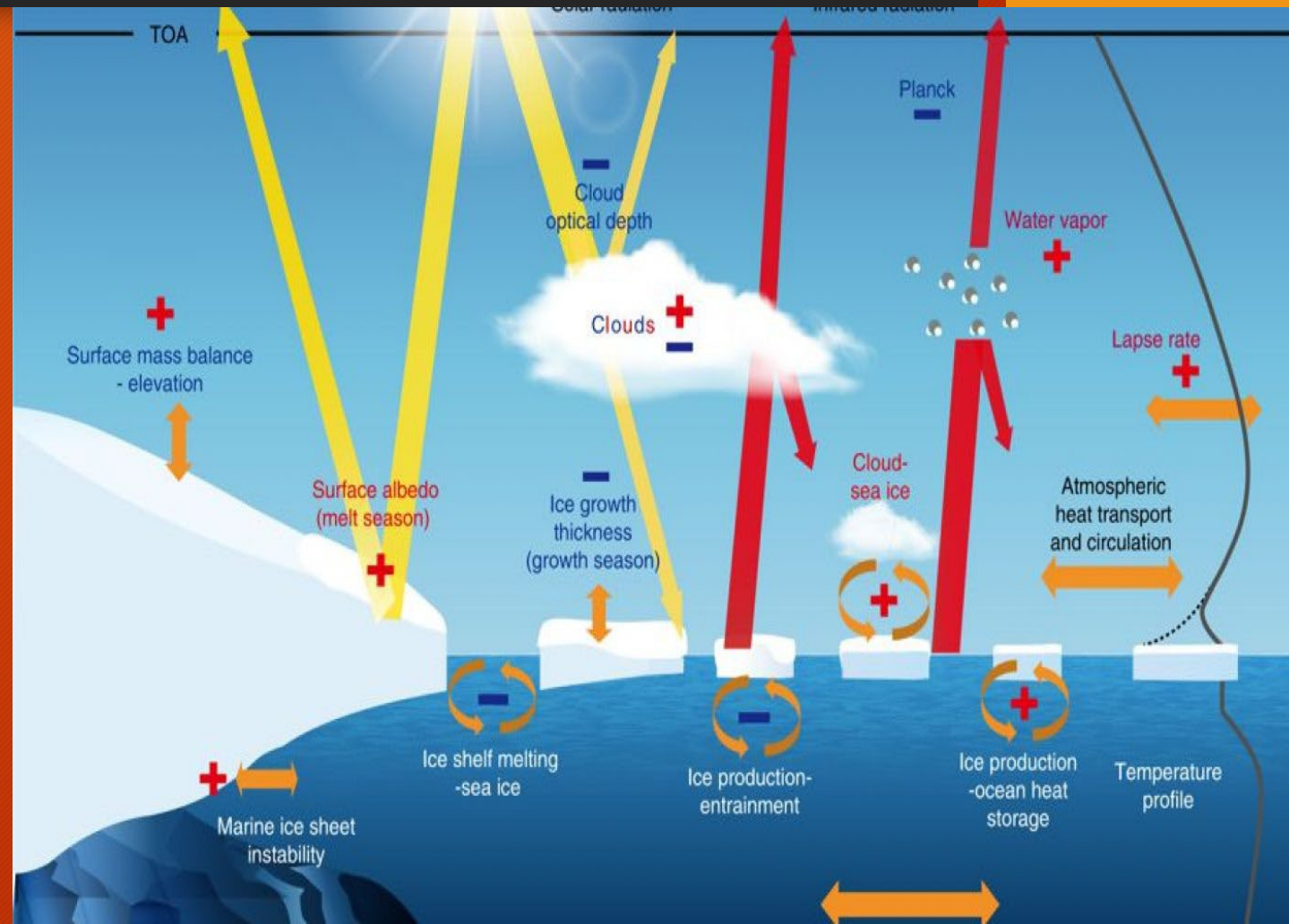
- Chemical evolution → simple cells
- Photosynthesis → oxygen-rich atmosphere
- Simple cells → complex cells → multicellular life
- Then → rapid explosion of animal diversity

Is it possible for Earth to completely freeze?



Hypotheses - Potential contributing factors

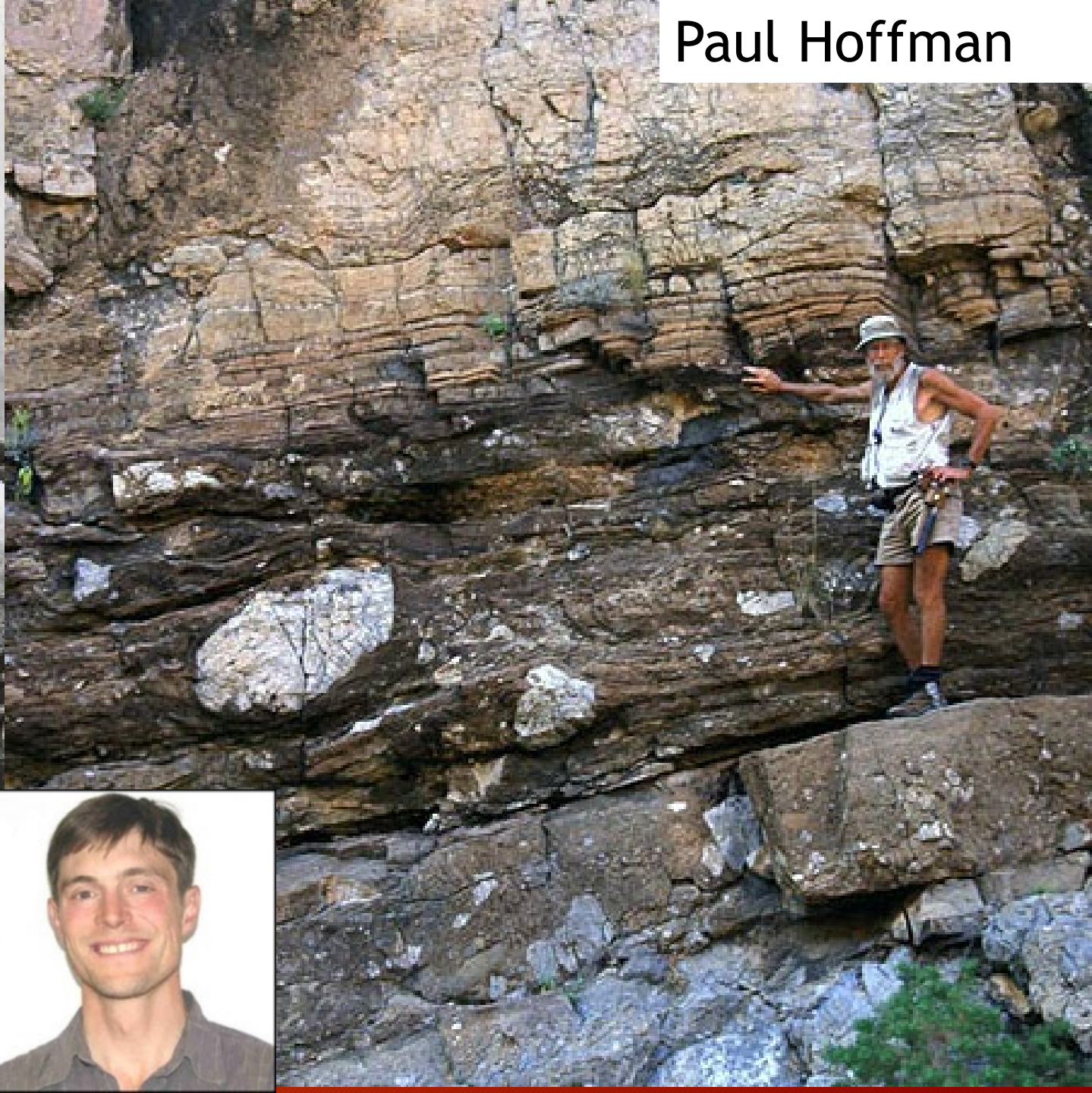
- Winter snow must extend into and through summer
- Solar radiation was 6% less lower than today
 - H to He, increased core density
- Neoproterozoic Supercontinent
 - Rodinia, equatorial, easier for intercontinental glacial expansion
- Positive Feedback
 - Glacial albedo



Grant Young



Paul Hoffman



Neoproterozoic

Ediacaran 635
Cryogenian Ma
Tonian 720

541 Ma
1000

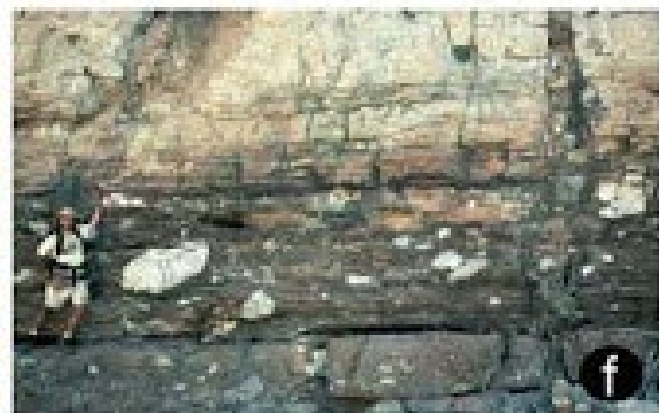
- Till vs Tillite
- Iceberg deposited dropstones
 - Even along the Equator

Gaskiers 582
584

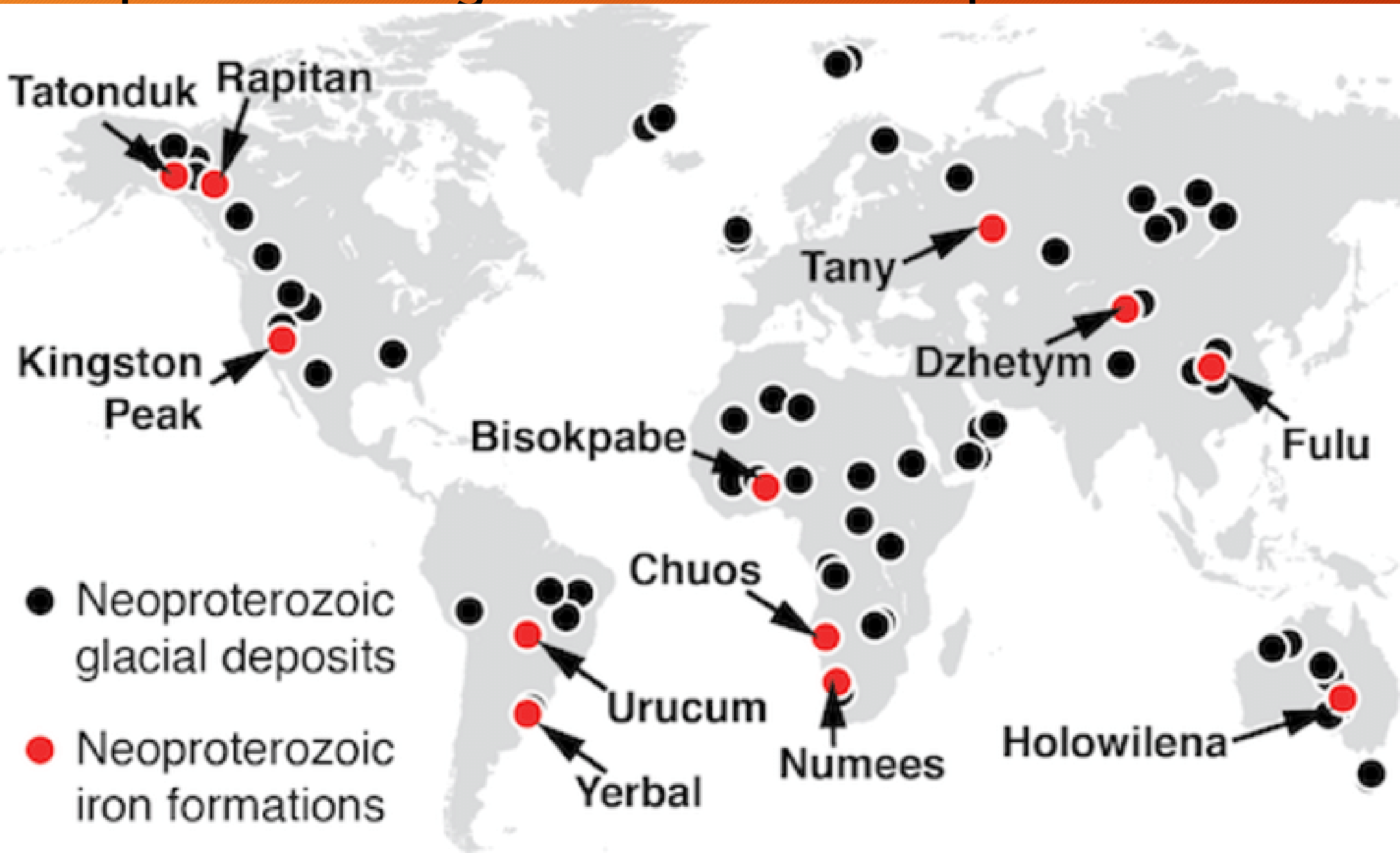
Marinoan 635
650

Sturtian 660
750

<https://francismacdonald.fas.harvard.edu/>
<https://cool.geol.ucsb.edu/people/francis-macdonald>



Neoproterozoic glacial and iron deposits



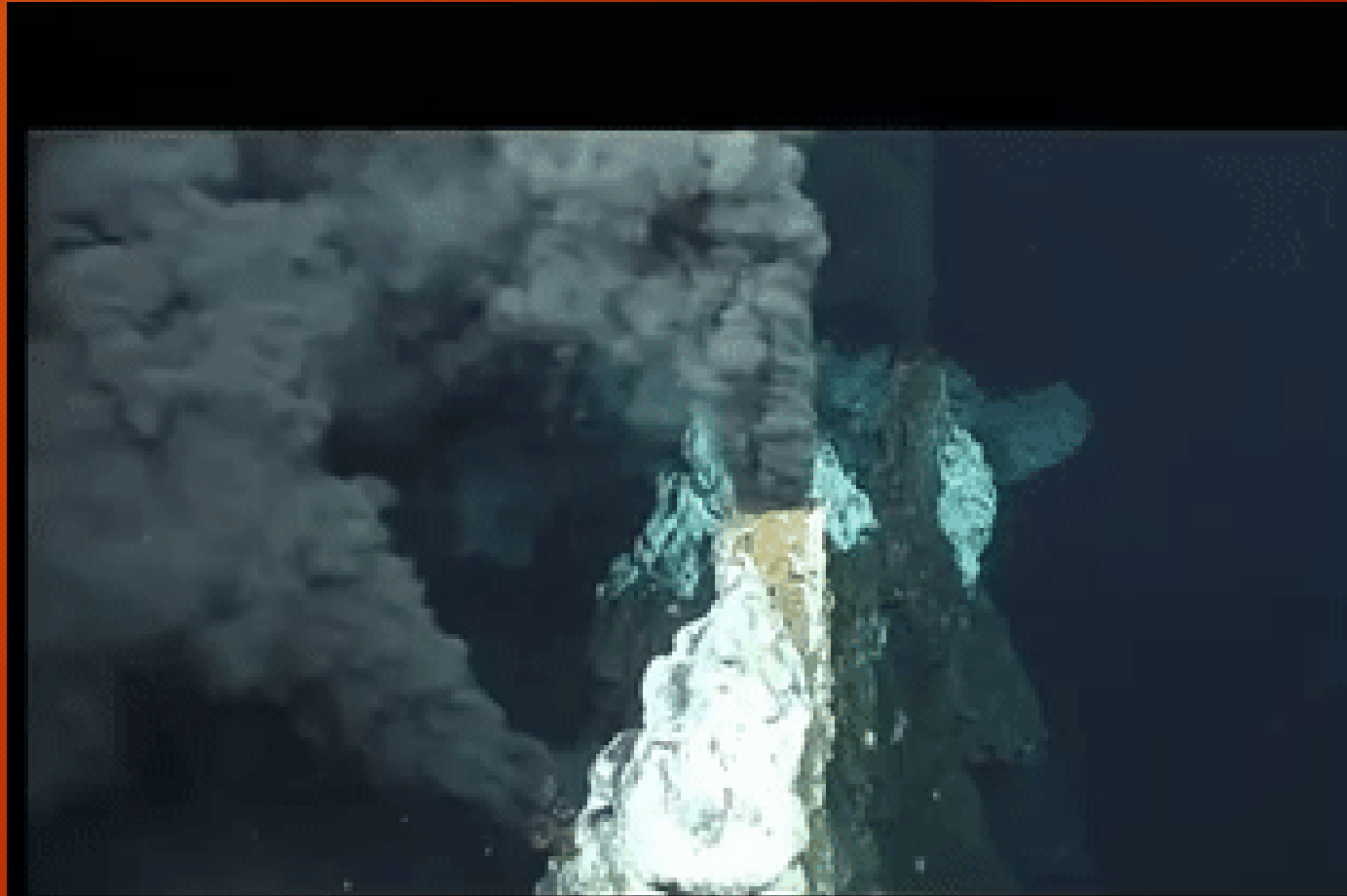
541
Ma
1000

Banded Iron Formations (BIF)

Stopped then Began again



- Initial Hypothesis -
 - Started again in correlation with glaciations because O_2 concentration was low due to increased ice cover' Similar to Archean Seas...
- Current hypothesis
 - O_2 isn't the most important factor, Rather BIF are common during increased seafloor hydrothermal activity
 - BIFs were developed during glacial retreat, causing sea level to rise



Evidence for...

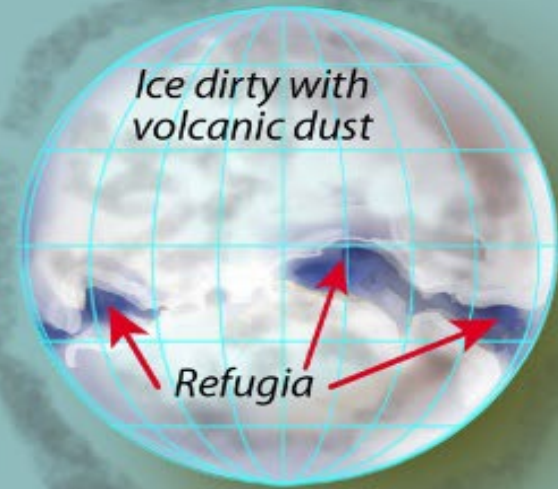
- If the oceans were frozen, they would become depleted in O_2 because photosynthesis from phytoplankton would end.
- And aerobic bacteria would continue until all dissolved O_2 would be used.

Against...

- There are no oceanic Mass extinctions during the Neoproterozoic
- There is evidence of dropstones in both Sturtian and Marinoan Tillites.

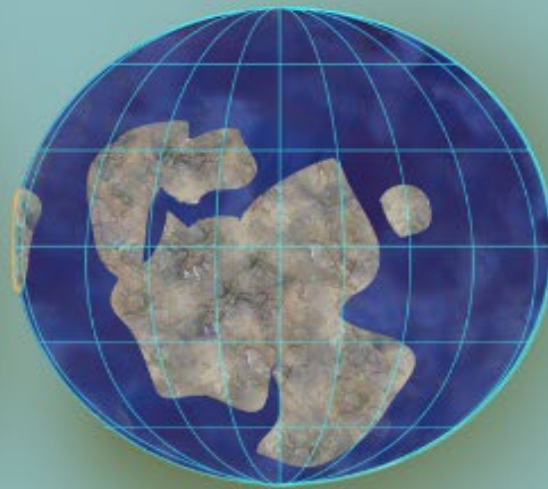


Dynamic Snowball: two long-lived glaciations

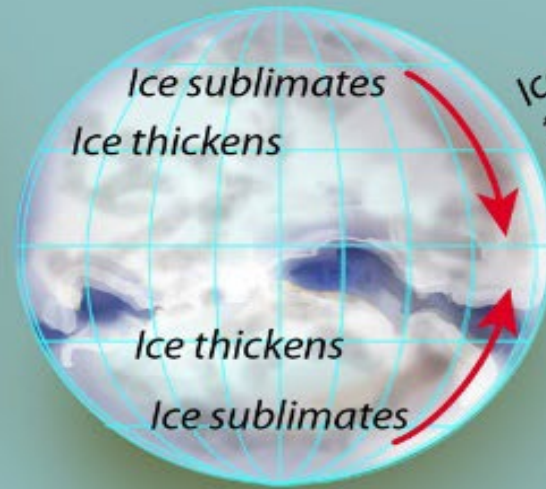


Lots of ash in air from volcanic eruption cools Earth

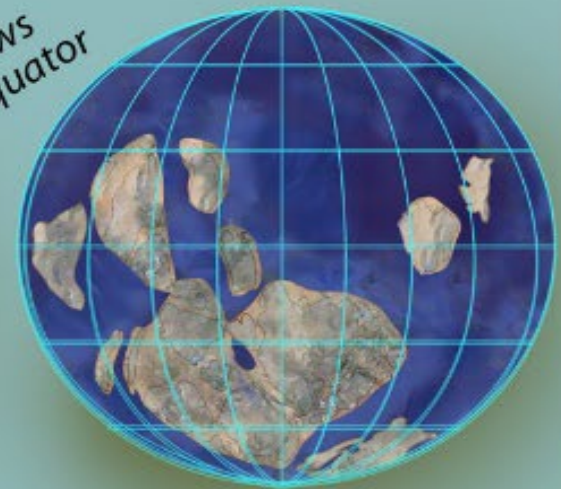
716.5 MYA



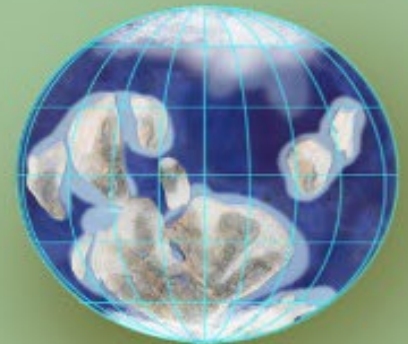
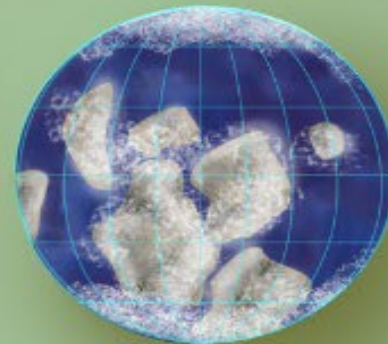
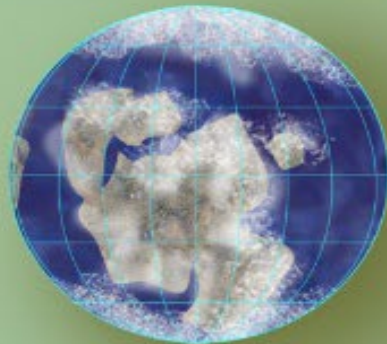
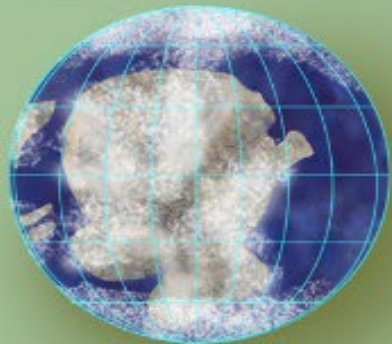
670 MYA



635 MYA



630 MYA

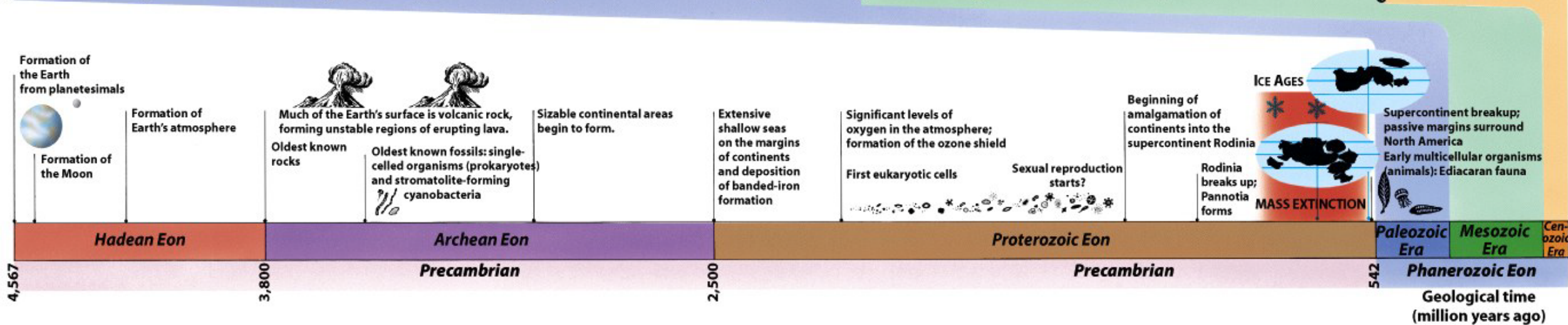
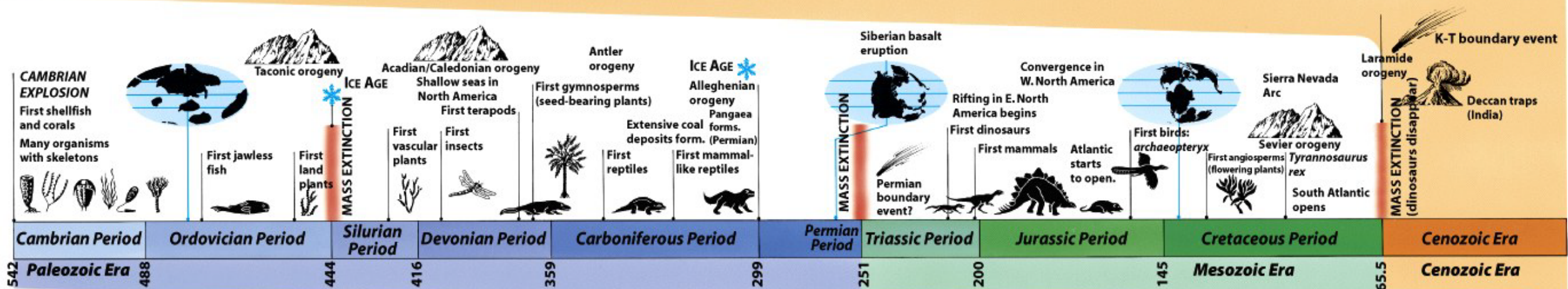
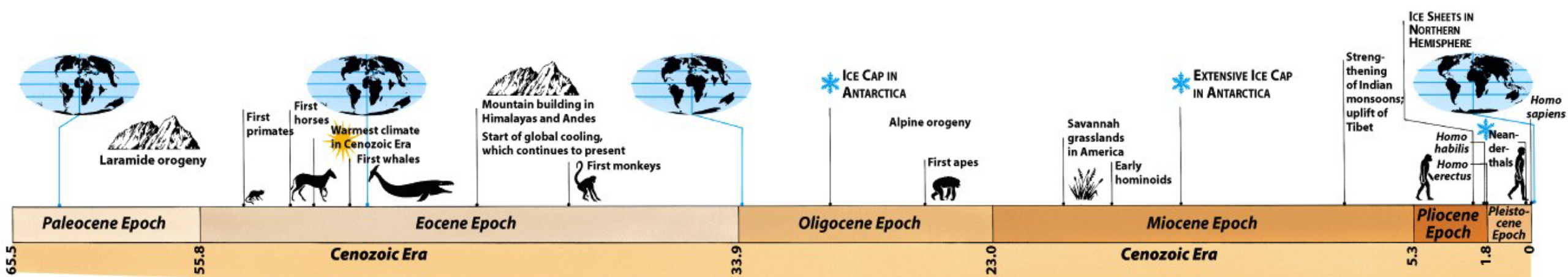


Another theory: glaciations patchy, short

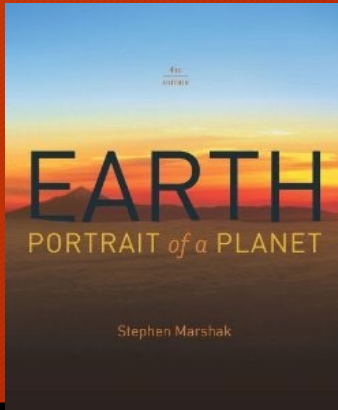
Precambrian - The Oldest Rocks

541 Ma
to
4.6 Ga

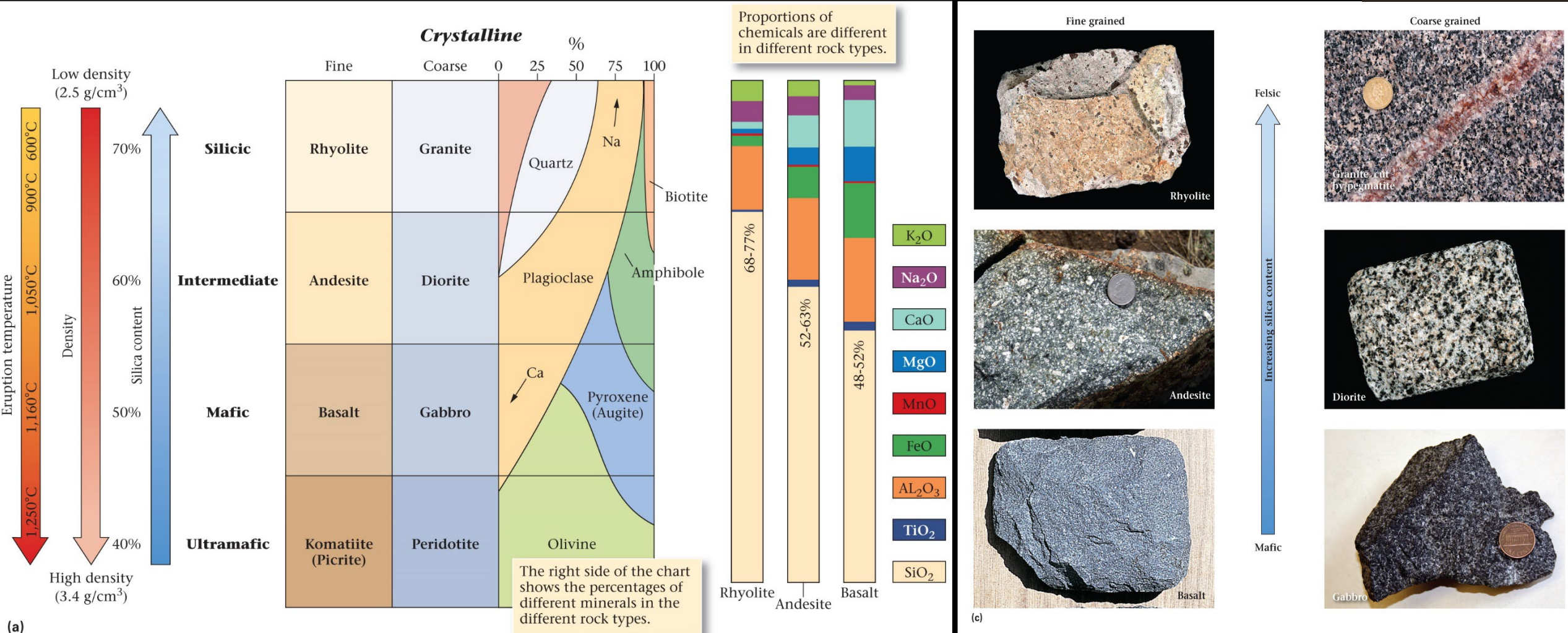
- Iowa's geologic history began approx. 3Ga ago with igneous and metamorphic rocks.
- Followed by mountain building events: Penokean, Central Plains, and Eastern Granite-Rhyolite Province 'orogenies' a product of plate tectonics.
- Iowa's oldest exposed rock is the Sioux Quartzite (approx. 1.6 Ga)
- 1.1Ga North America and Iowa were nearly torn apart by the Mid-continent Rift System

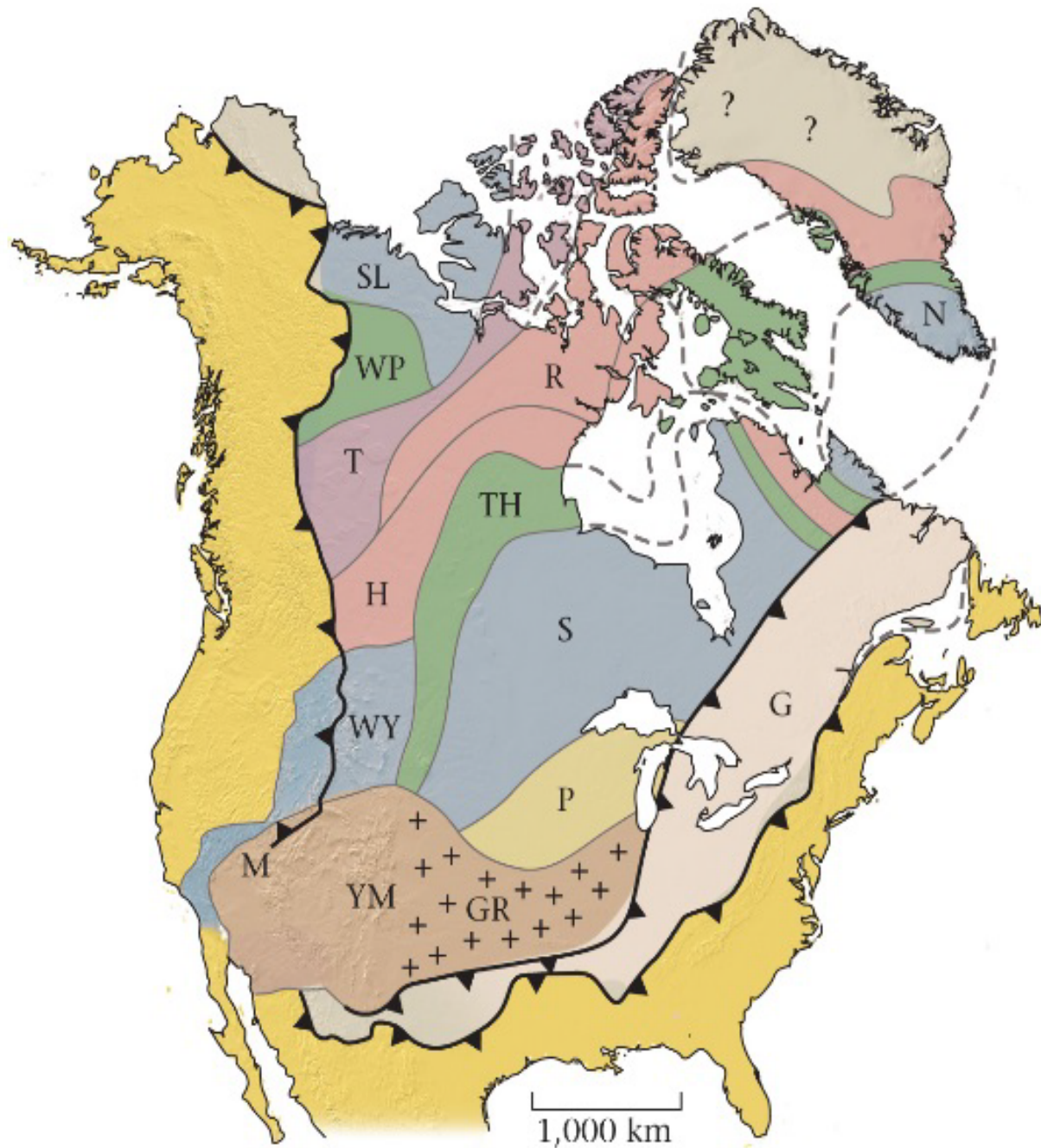


Geological time (million years ago)

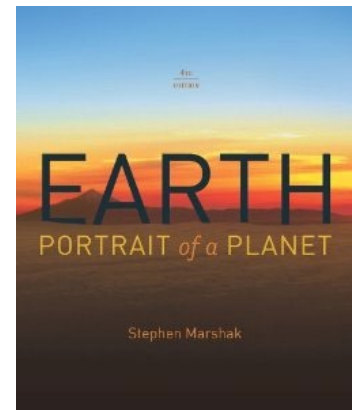


Extended concept (Igneous Intrusive vs Extrusive rocks)



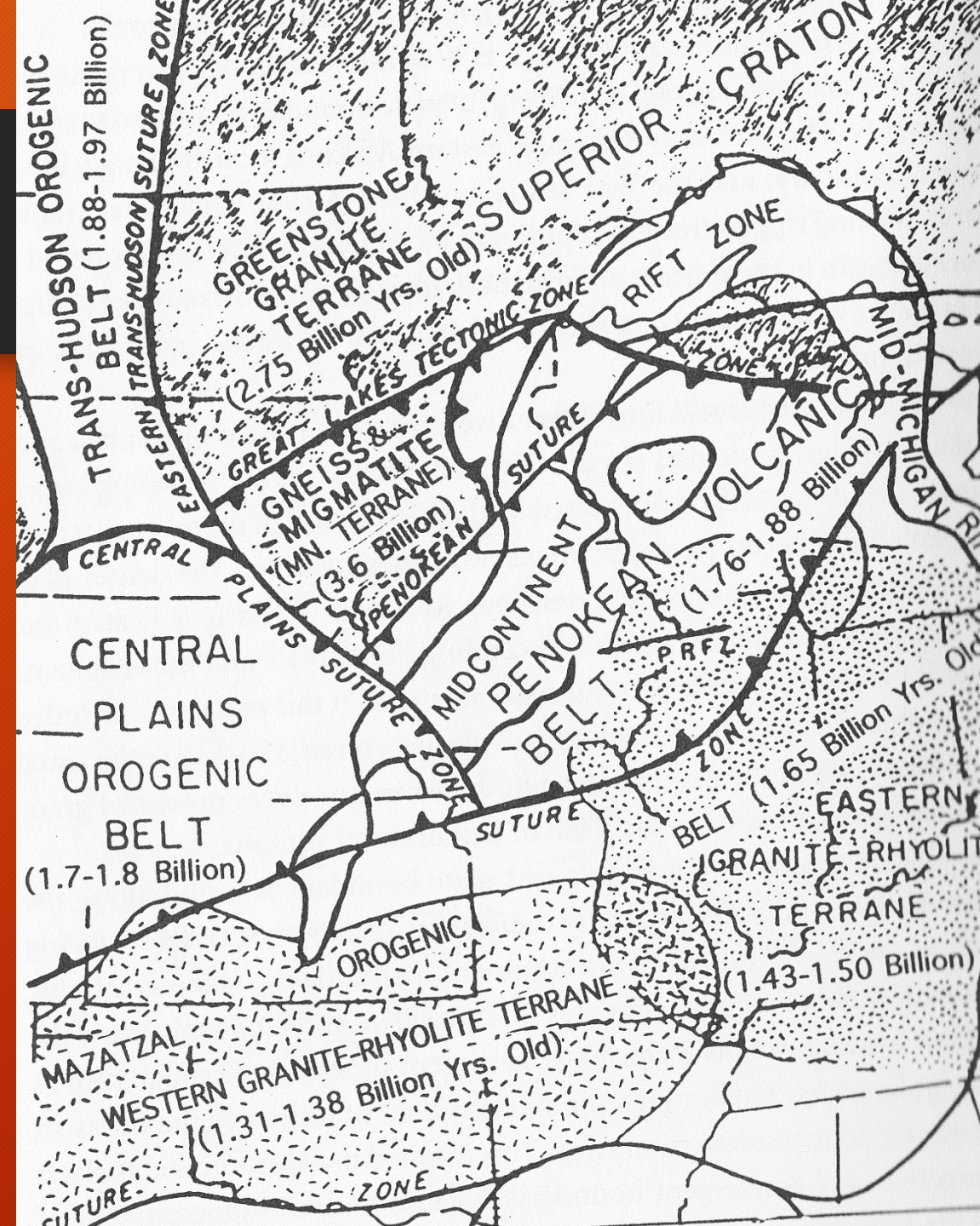


- Phanerozoic orogen
- 1.1- Ga collisional orogen (G = Grenville)
- 1.6- to 1.7- Ga accreted crust covered by granite and rhyolite, where patterned (GR = granite-rhyolite province)
- 1.6- to 1.7- Ga accreted crust (YM = Yavapai and Mazatzal)
- 1.8- Ga accreted crust (P = Penokean)
- 1.8- Ga collisional orogen (TH = Trans-Hudson; WP = Wopmay)
- 1.9- Ga collisional orogen (T = Thelon)
- Archean rocks, later deformed and metamorphosed in the Proterozoic (H = Hearn; R = Rae)
- Relicts of Archean crust (WY = Wyoming; M = Mojave; S = Superior; N = Nain; SL = Slave)



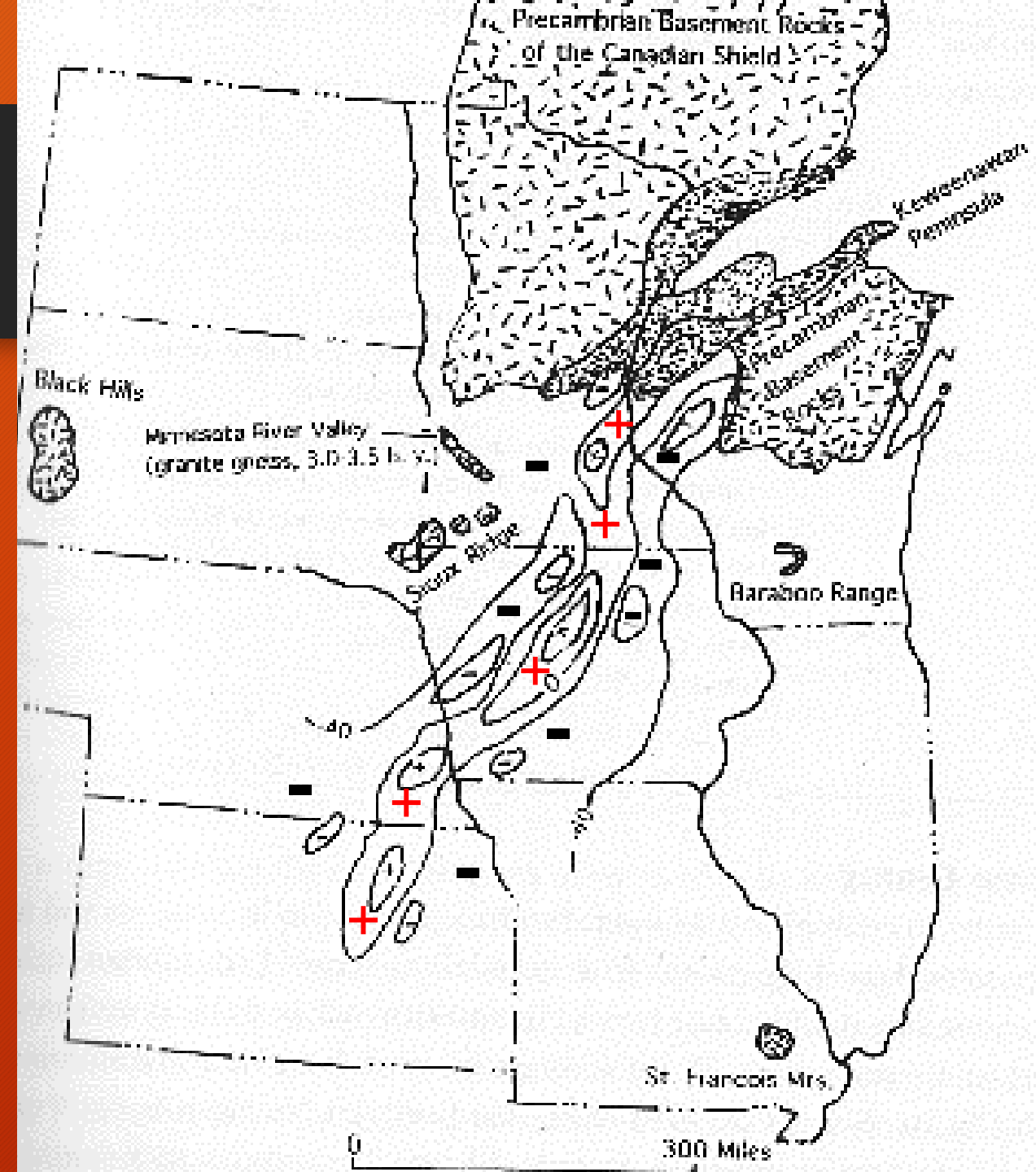
Regional Basement Structure

- Oldest rock = Minnesota tarrane 3.6Ga, Penokean Volcanic belt 1.8Ga, the Granite provenances in the south approx. 1.4Ga
- Black Hills Granite (famously represented by Mount Rushmore) via a Tertiary uplift/orogeny



Iowa's Igneous & Metamorphic 'Basement'

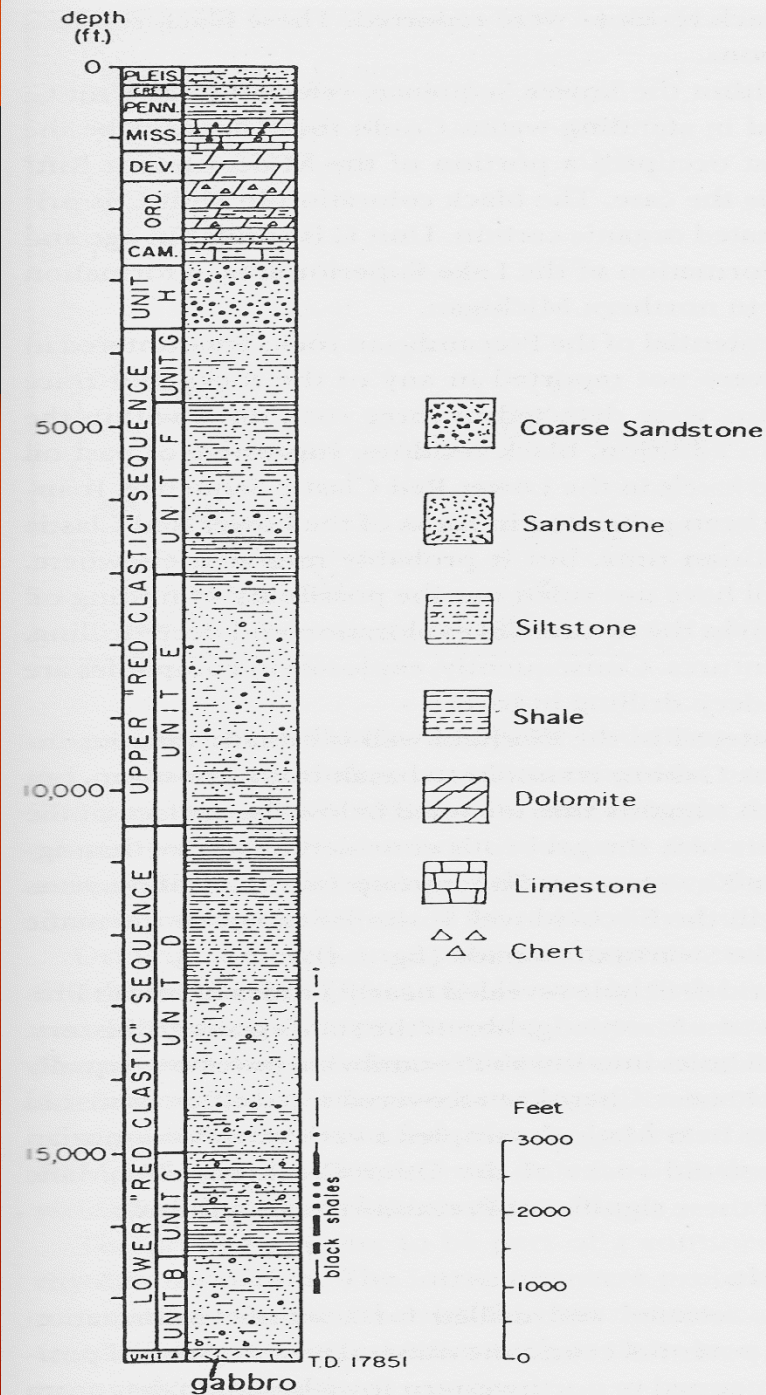
- Gravity surveys supplement direct observations (samples)
 - (+) anomalies indicate dense rock bodies i.e. basalt and gabbro
 - (-) anomalies indicate low density rocks i.e. sandstone and shale



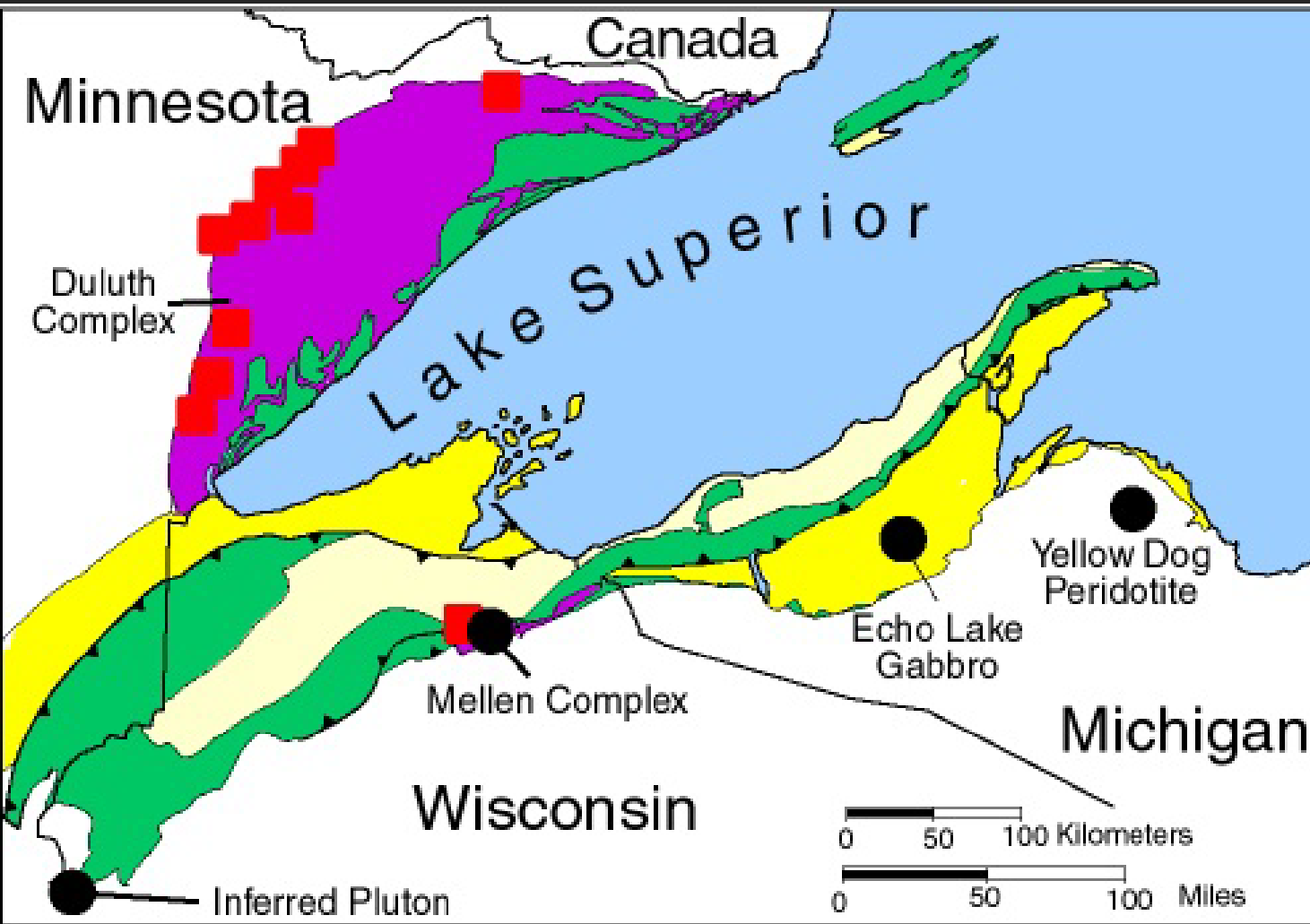
The Eischeid Well - Iowa's Deepest Drilled Well

- Carroll County
- Amaco Production Company
- 208 days of drilling to reach a depth of 17,851ft (one of the deepest in the Midwest!)
- \$20,000,000.00

Lower 'Red-clastic'
Upper 'Red-clastic'



Duluth Complex & North shore Lake Superior



EXPLANATION

-  Sandstone
-  Gabbro
-  Basalt
-  Known nickel and copper sulfide mineralization
-  Favorable target
-  Faults, in part defining the edge of the rift



BIF

2.2 Ga

to

2.4 Ga





Exploration for Platinum Group Element Mineralization in Northeast Iowa



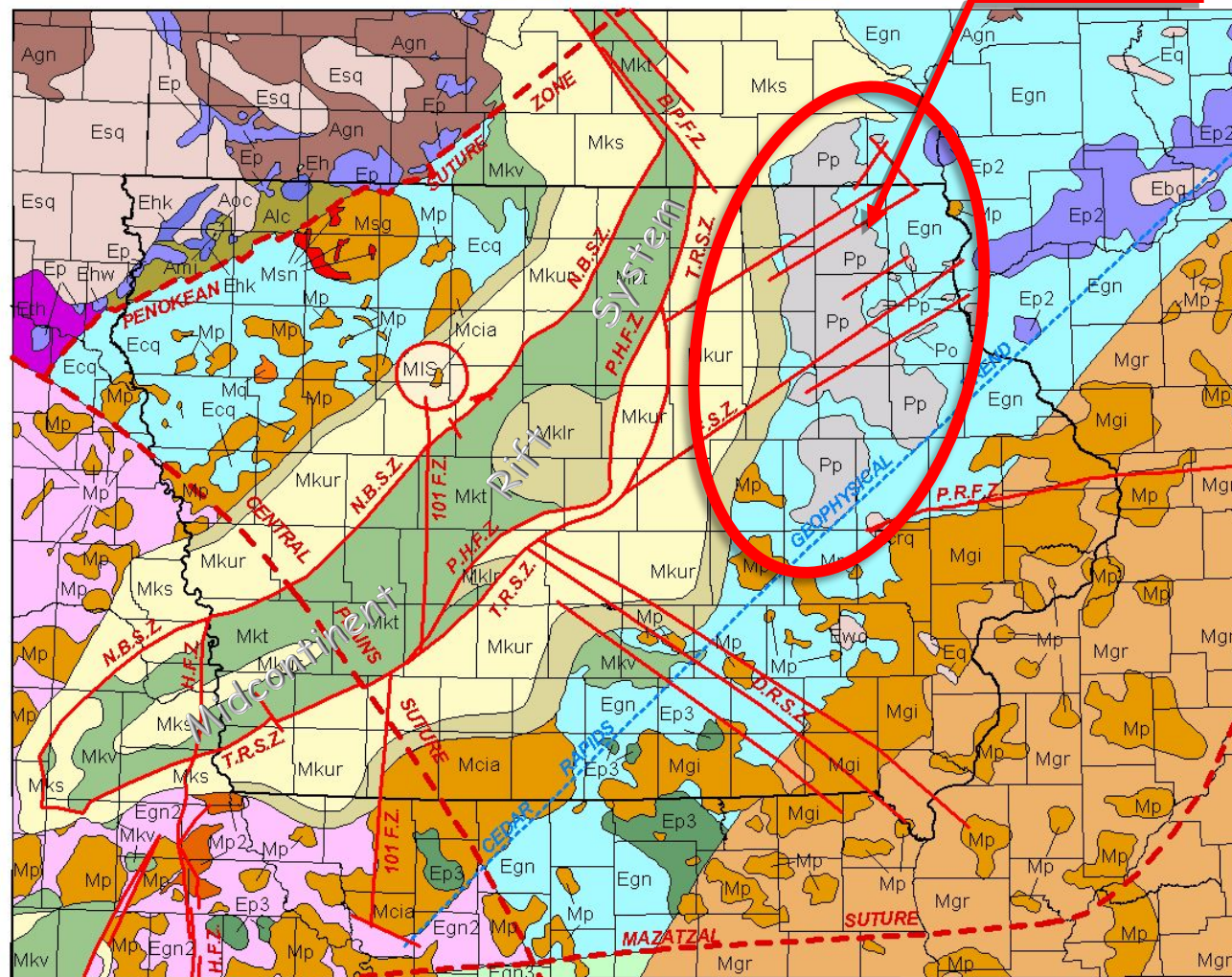
Ray Anderson & Ryan Clark
Iowa Geological & Water Survey



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) Keewenawan Clastic Sedimentary Rocks
 - (Mkur) Keewenawan Upper Red Clastic Group
 - (Mklr) Keewenawan Lower Red Clastic Group
 - (Mkv) Keewenawan Volcanic / Plutonic Rocks
 - (Mkt) Keewenawan 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
 - (Eqq) Baraboo Quartzite
 - (Esq) Sioux Quartzite
 - (Ecq) 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
 - (Eqq) Camp Quest Gneiss (2065 ± 10 Ma)
- Trans-Hudson Orogenic Belt
- (Eth) Granite and gneiss dominant

- ARCHEAN (>2500 Ma)**
- (Alc) Lyon County Gneiss (2523 ± 5 Ma)
 - (Ami) Matlock Banded Iron Formation
 - (Aoc) Otter Creek Mafic Complex (2830 ± 90 Ma)
 - (Agn) Early to Middle Archean gneiss and migmatite terrane

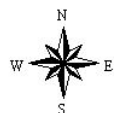
- ROCKS OF UNCERTAIN AFFINITIES**
- (Mcia) Central Iowa Arch Granites
 - (Po) Osborne Mafic Complex
 - (Pp) Northeast Iowa Plutonic Complex

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

- known or inferred faults
- - - Proterozoic sutures
- ~ ~ ~ geophysical trend

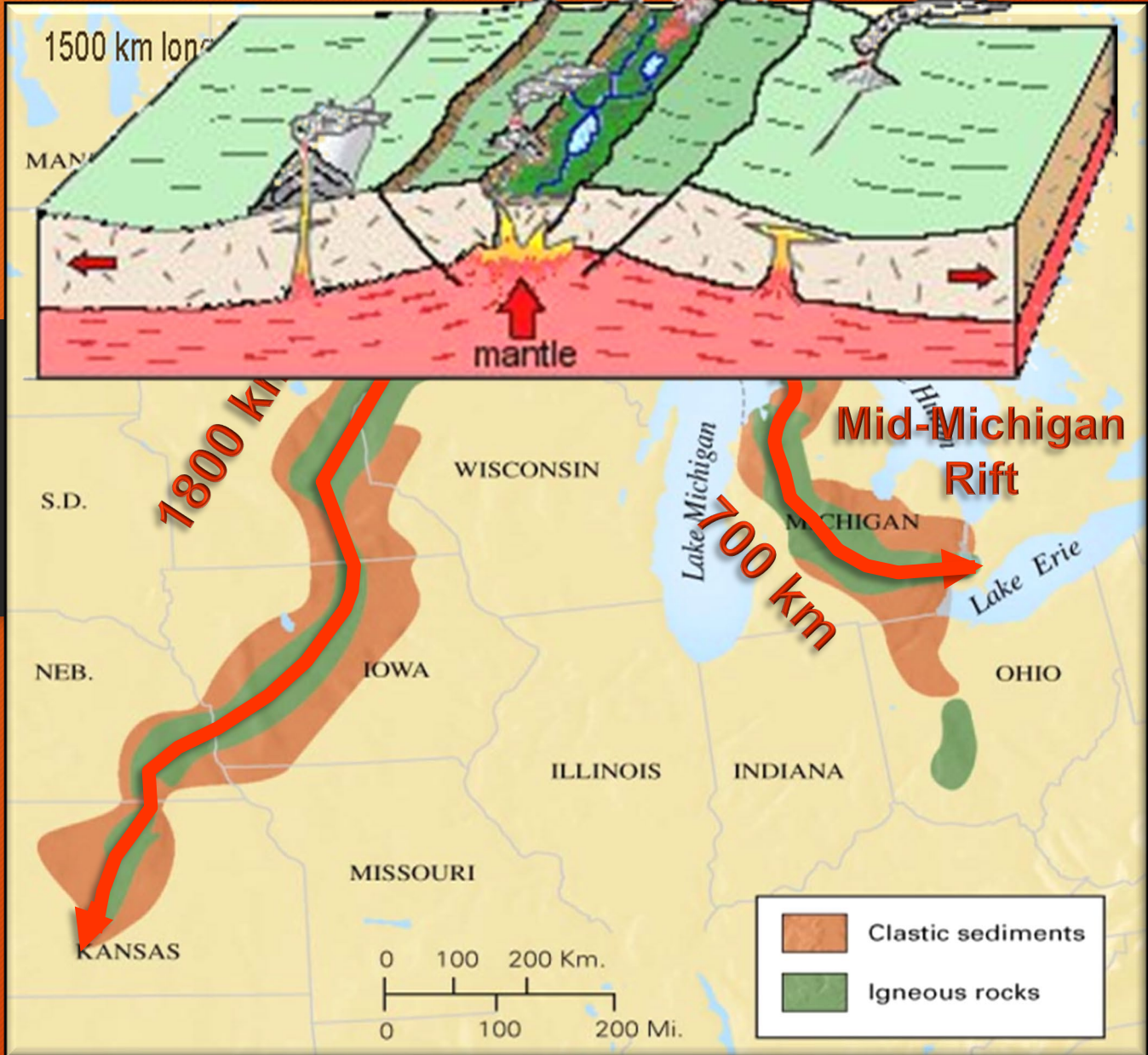
key to mapped faults

- | | |
|---|---|
| N.B.F.Z. N.B.F.Z. Northern Boundary Fault 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 | |

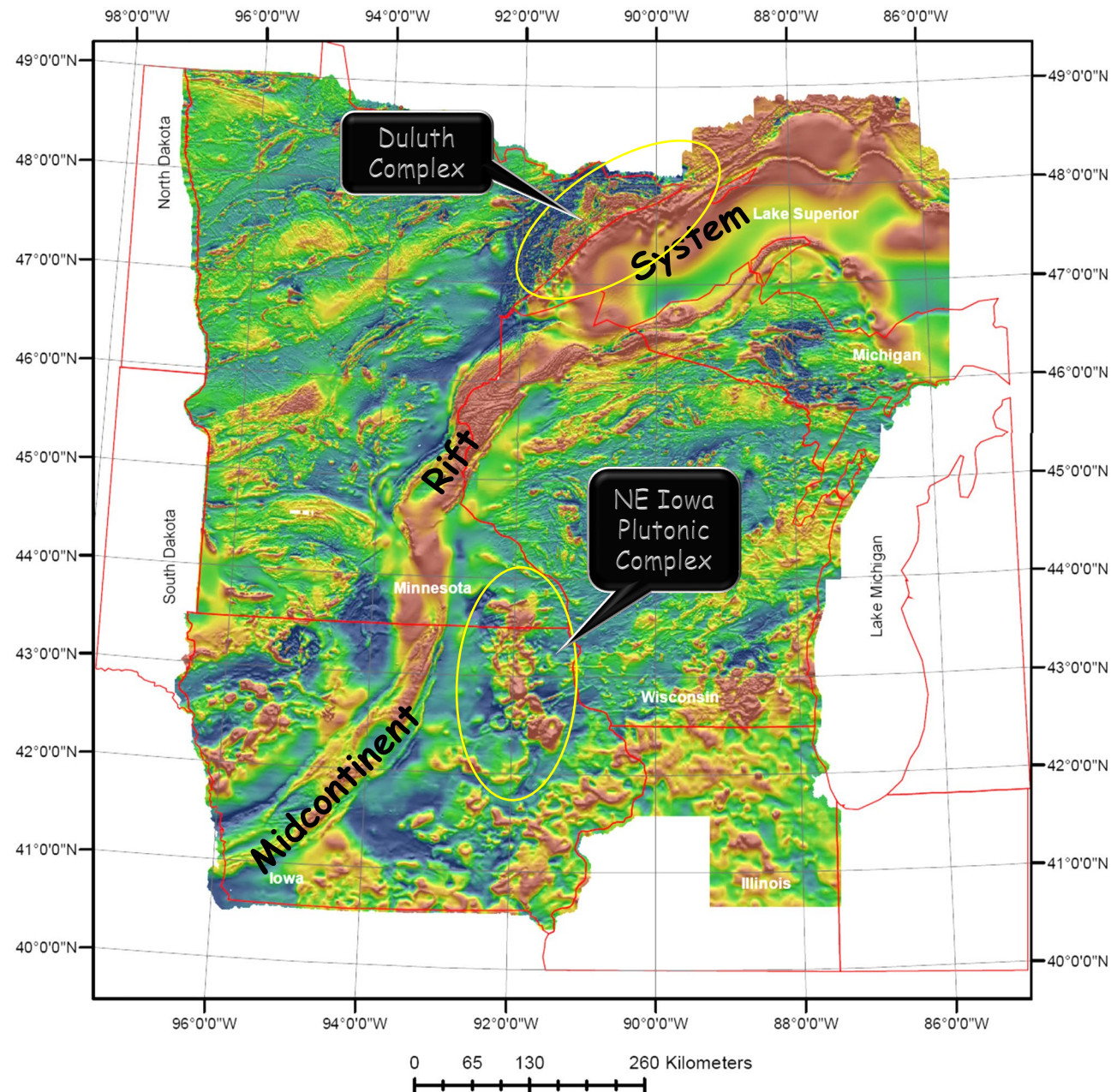


0 100 Miles

The Midcontinent Rift System



Shaded-Relief Total Magnetic Intensity Anomaly



NanoTesla



High : 30661.777344

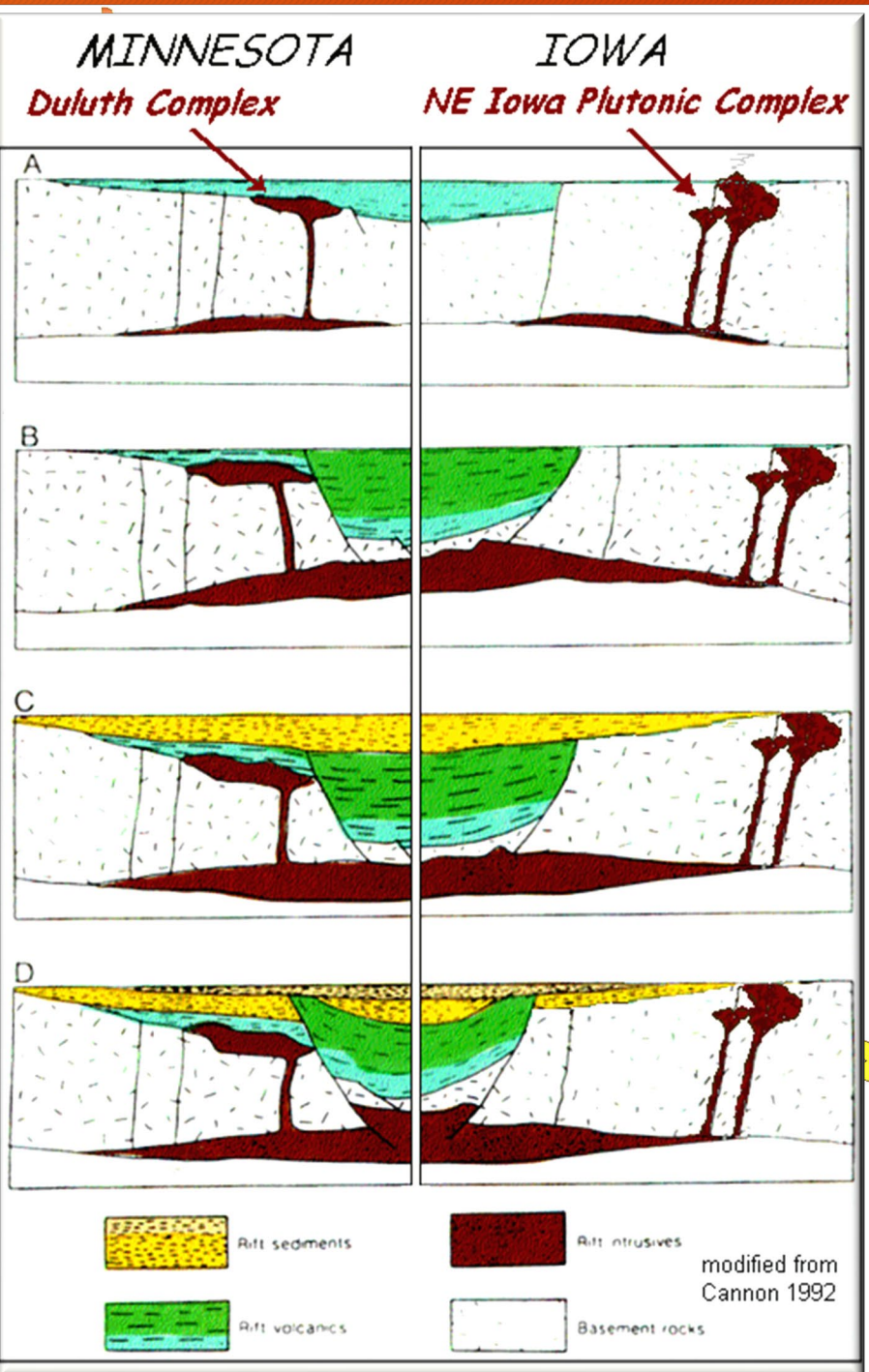
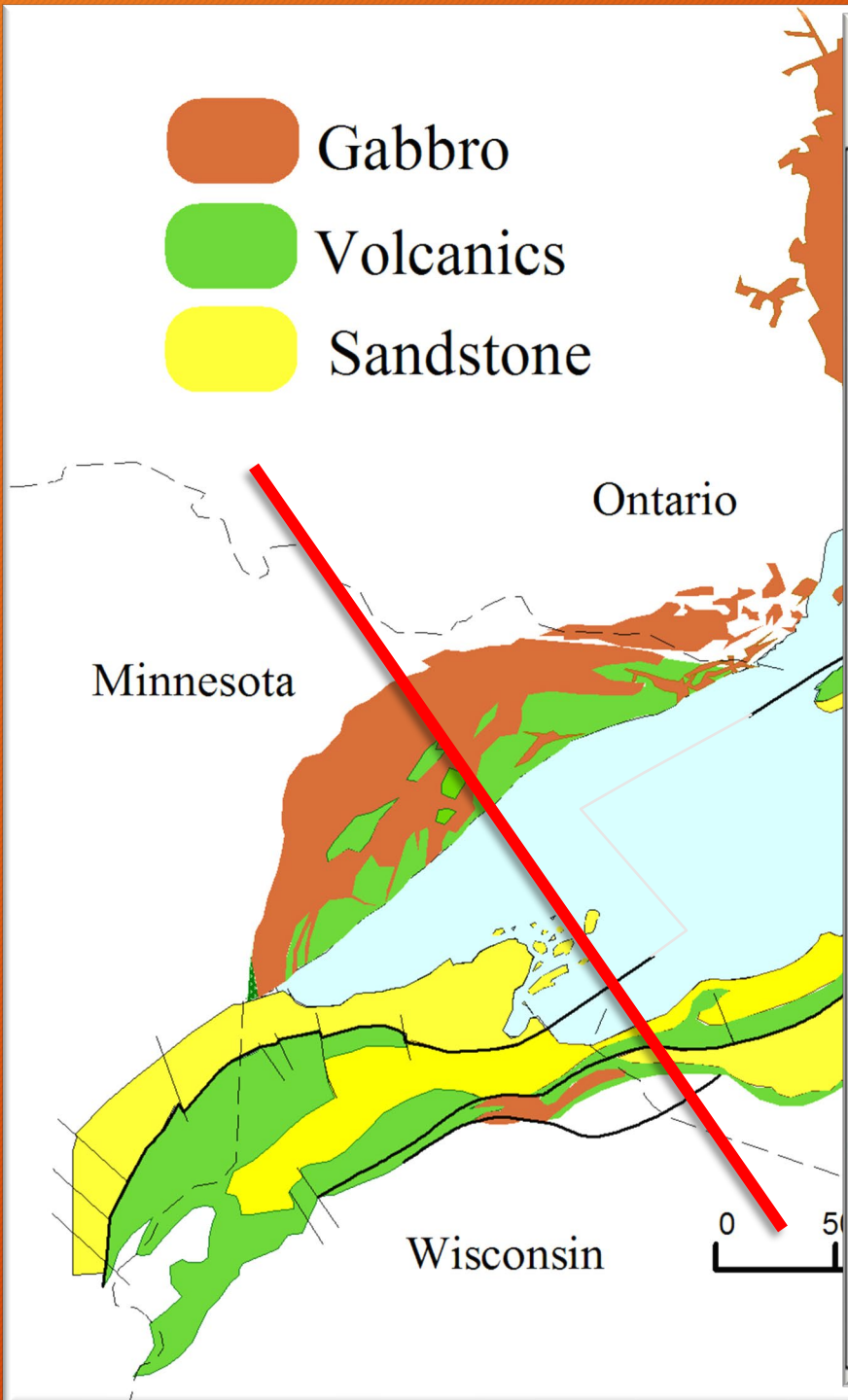
Low : -9982.036133

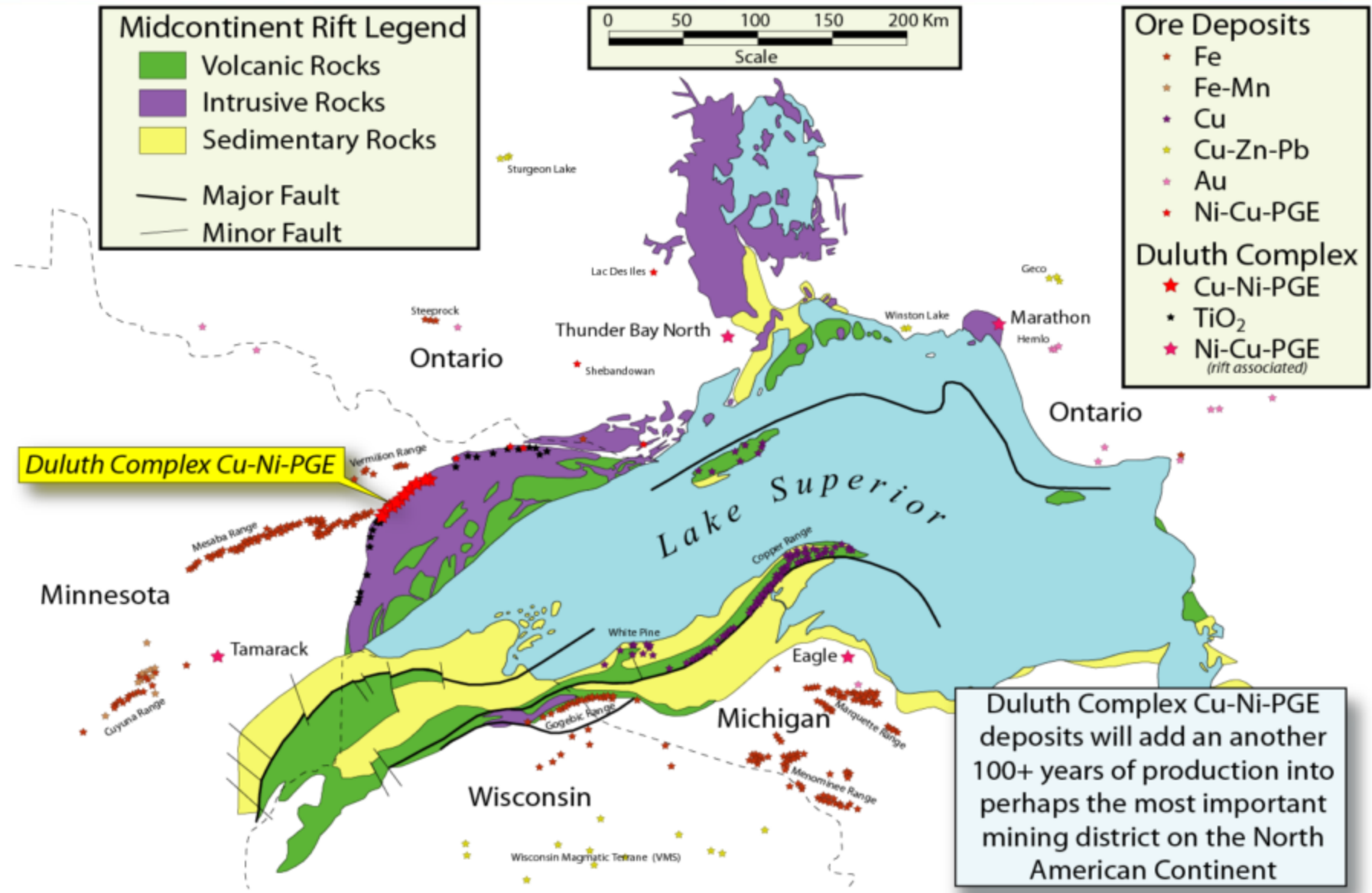
Shaded-relief map of the total magnetic intensity anomaly for the north-central United States. Data compiled by David L. Daniels and Stephen L. Snyder of the U.S. Geological Survey from various sources. Most of Minnesota was flown with a line spacing of 400 meters and an elevation (above land surface) 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.](http://www.gsi.gov/crustal-imaging-and-characterization-team)

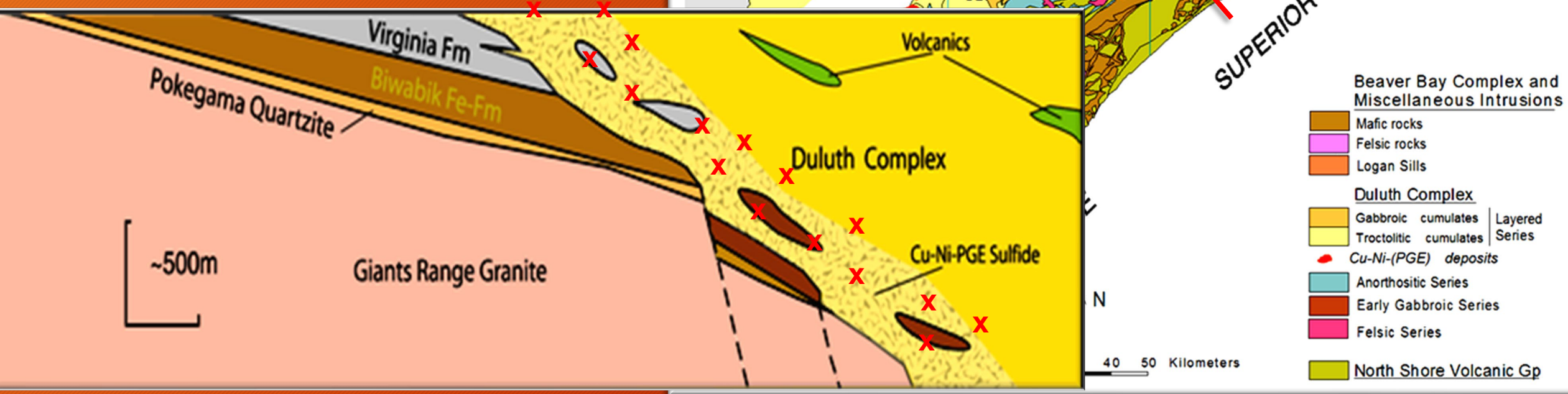
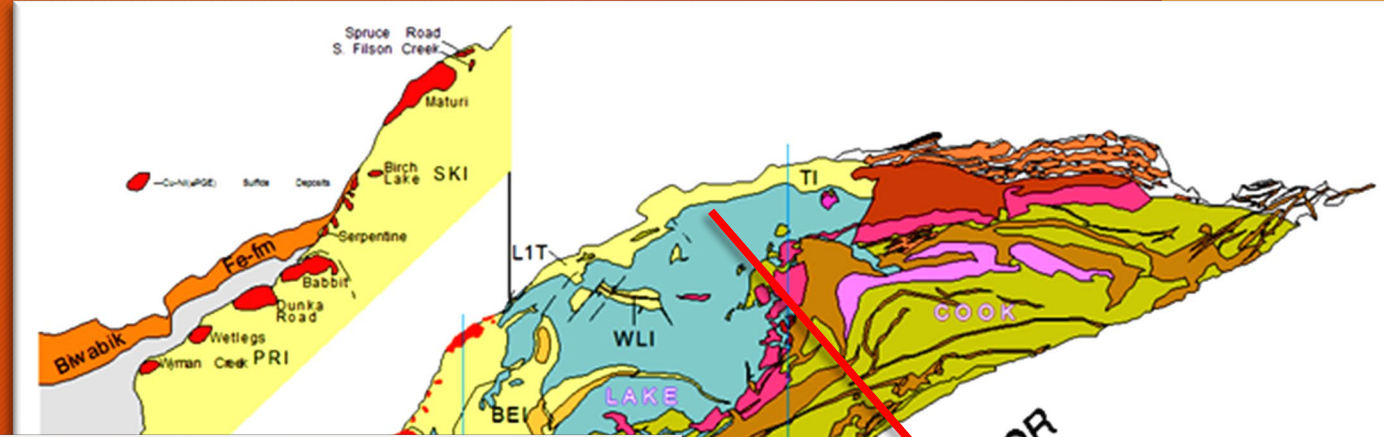
Aeromagnetic data in Minnesota were acquired by the Minnesota Geological Survey (MGS), with support from the Legislative Commission on Minnesota Resources. Aeromagnetic data in Wisconsin were acquired with support from the Wisconsin Geological and Natural History Survey and the U. S. Geological Survey.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

-  Gabbro
-  Volcanics
-  Sandstone

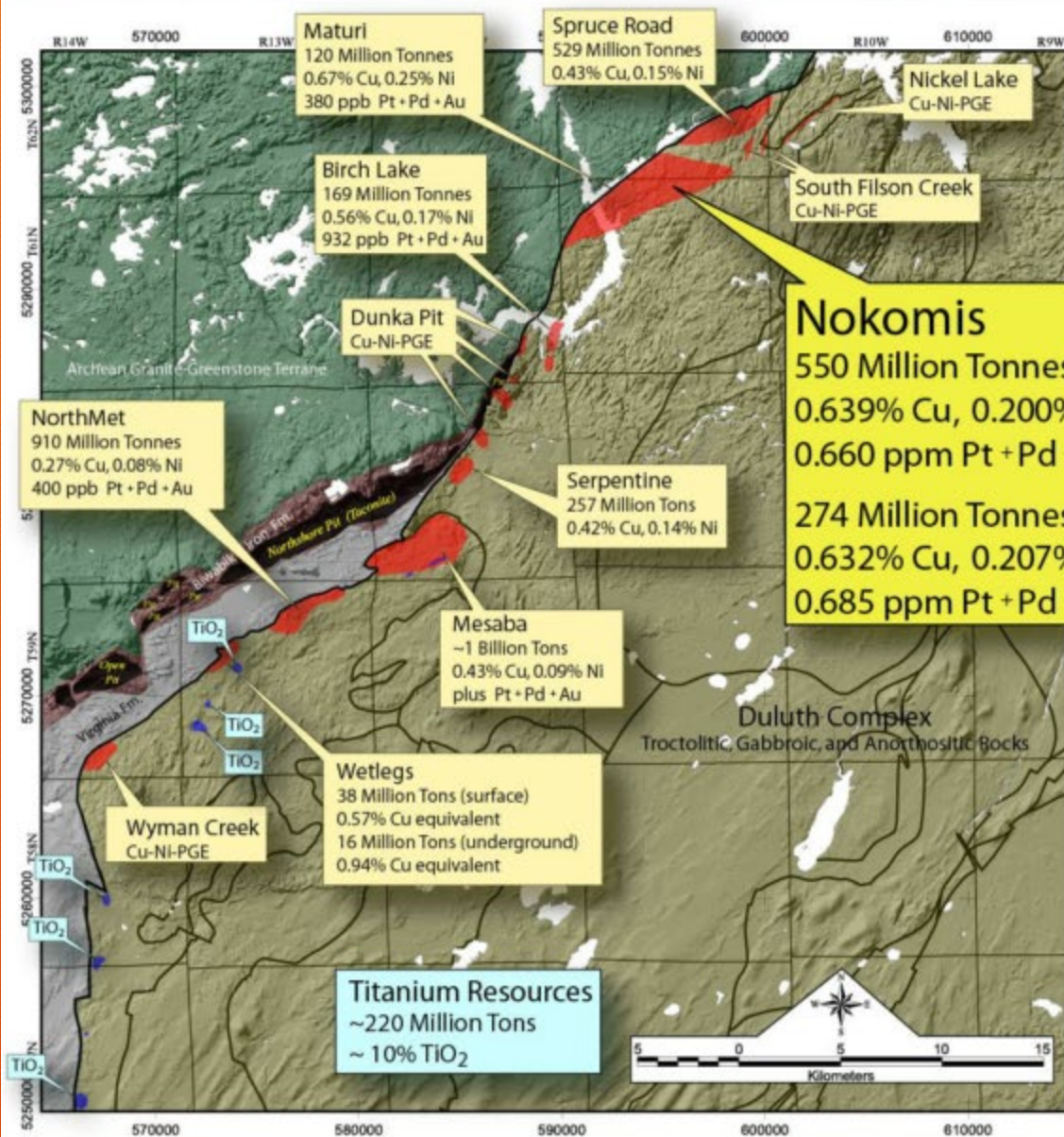




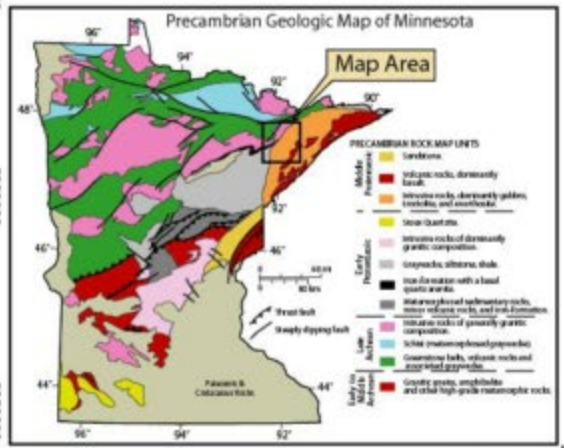
The Cu-Ni-PGE Deposits of the Duluth Complex



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



Nokomis
550 Million Tonnes Indicated
0.639% Cu, 0.200% Ni
0.660 ppm Pt + Pd + Au
274 Million Tonnes Inferred
0.632% Cu, 0.207% Ni
0.685 ppm Pt + Pd + Au



Updated TMM December 2012 Resource Estimate



Contained Metals in TMM NI 43-101 Resource*

	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.

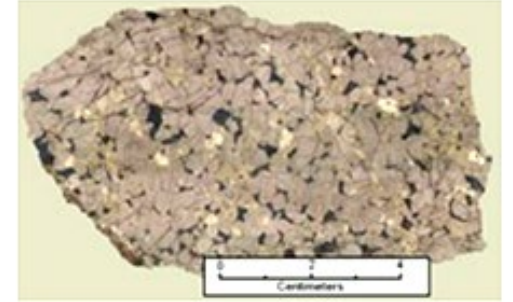
"The Duluth Complex is perhaps the world's largest untapped resource of (copper, nickel and platinum group metals) with **multibillion tons** of geologic resources estimated to be worth more than **\$1 trillion**," stated a 2007 report by geologists at the Natural Resources Research Institute of the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



Stillwater ●
 Pt <5%
 Pd 90%
 Rh <5%

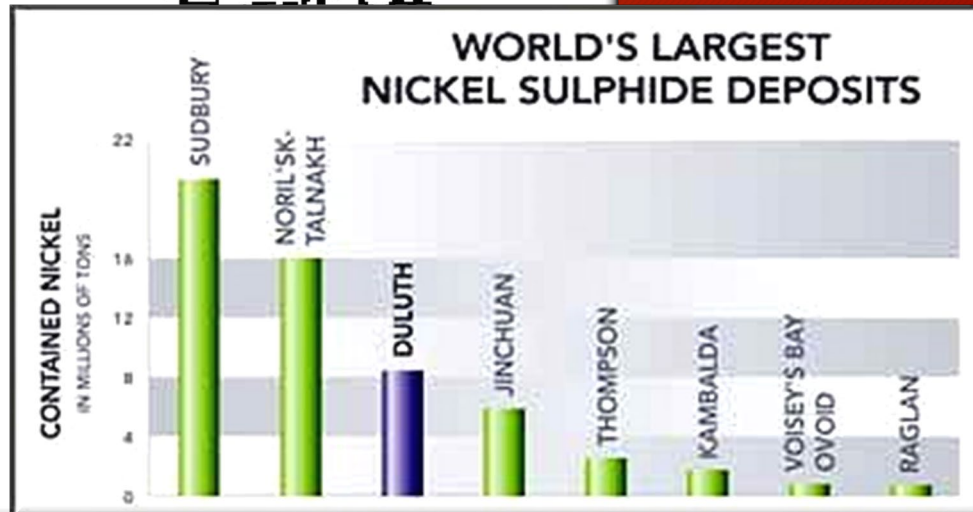
Fenno-Scandian ○

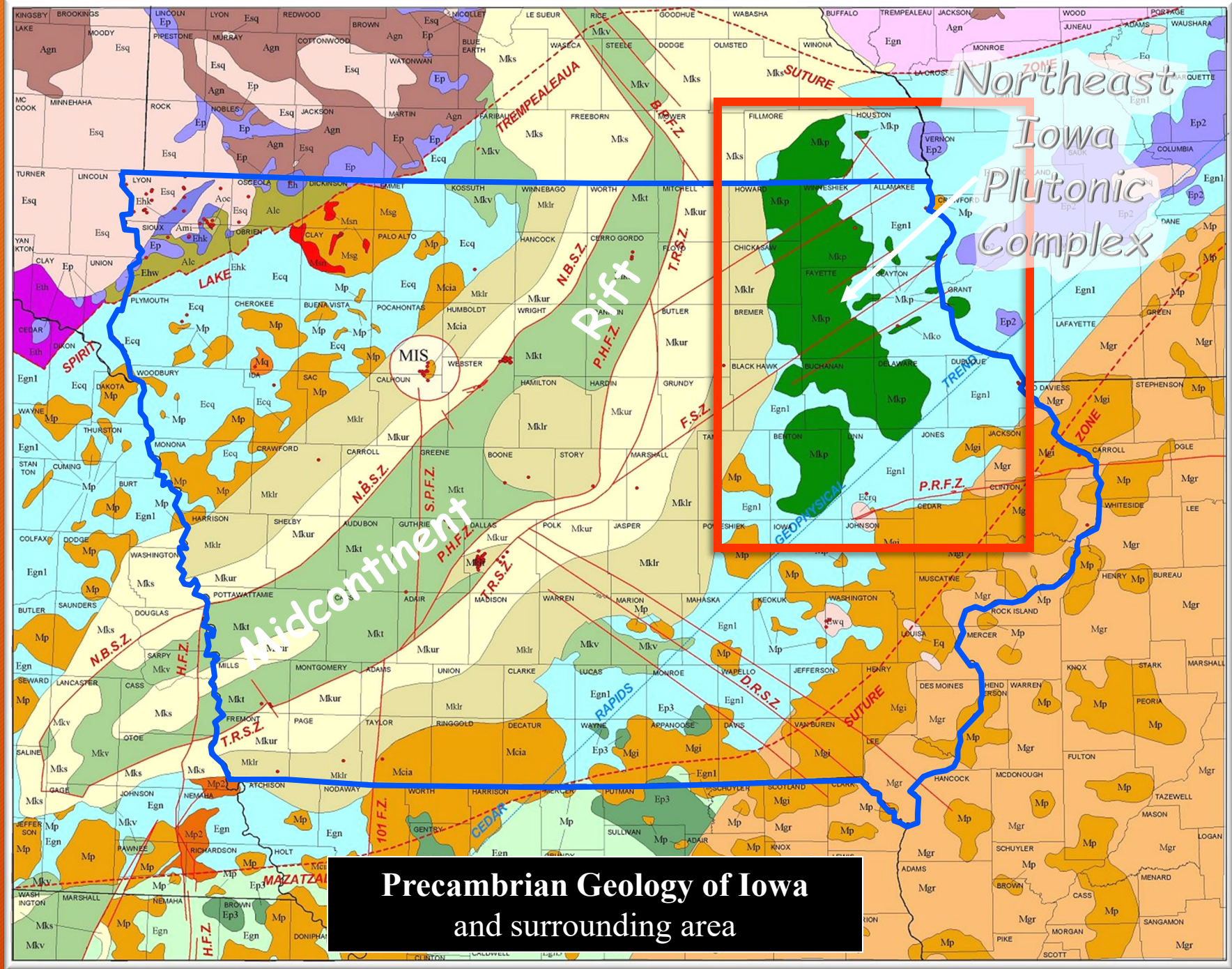
Noril'sk ●
 Pt 18%
 Pd 67%
 Rh 36%

Jinchuan ○

Great Dyke ●
Bushveld ●
 Pt 74%
 Pd 24%
 Rh 60%

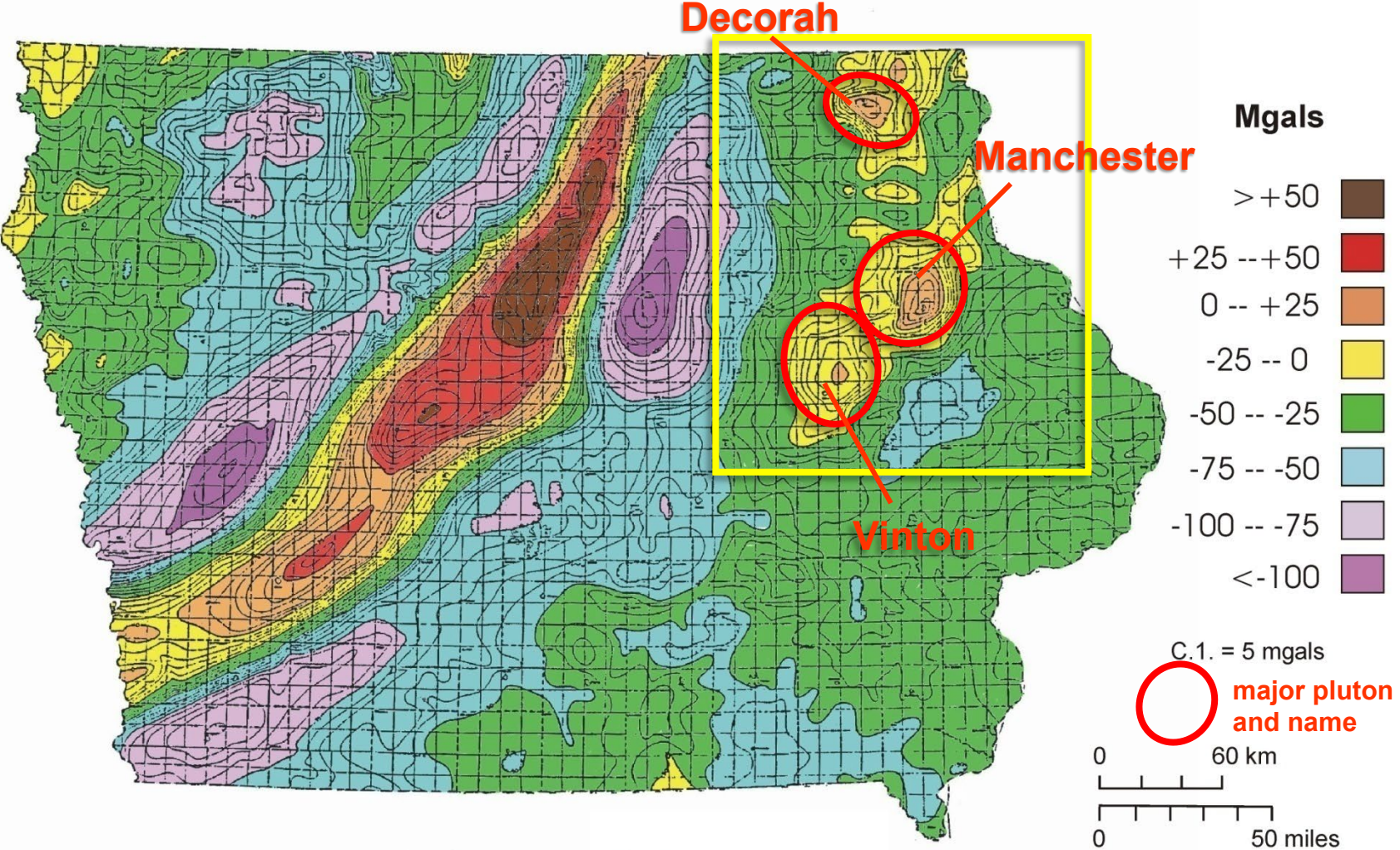
- PGE-reefs in Ultramafic/Mafic Complexes
- PGE-reefs in Tholeiitic Intrusions
- PGE as by-product in Cu-Ni Sulfide Deposit



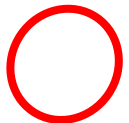
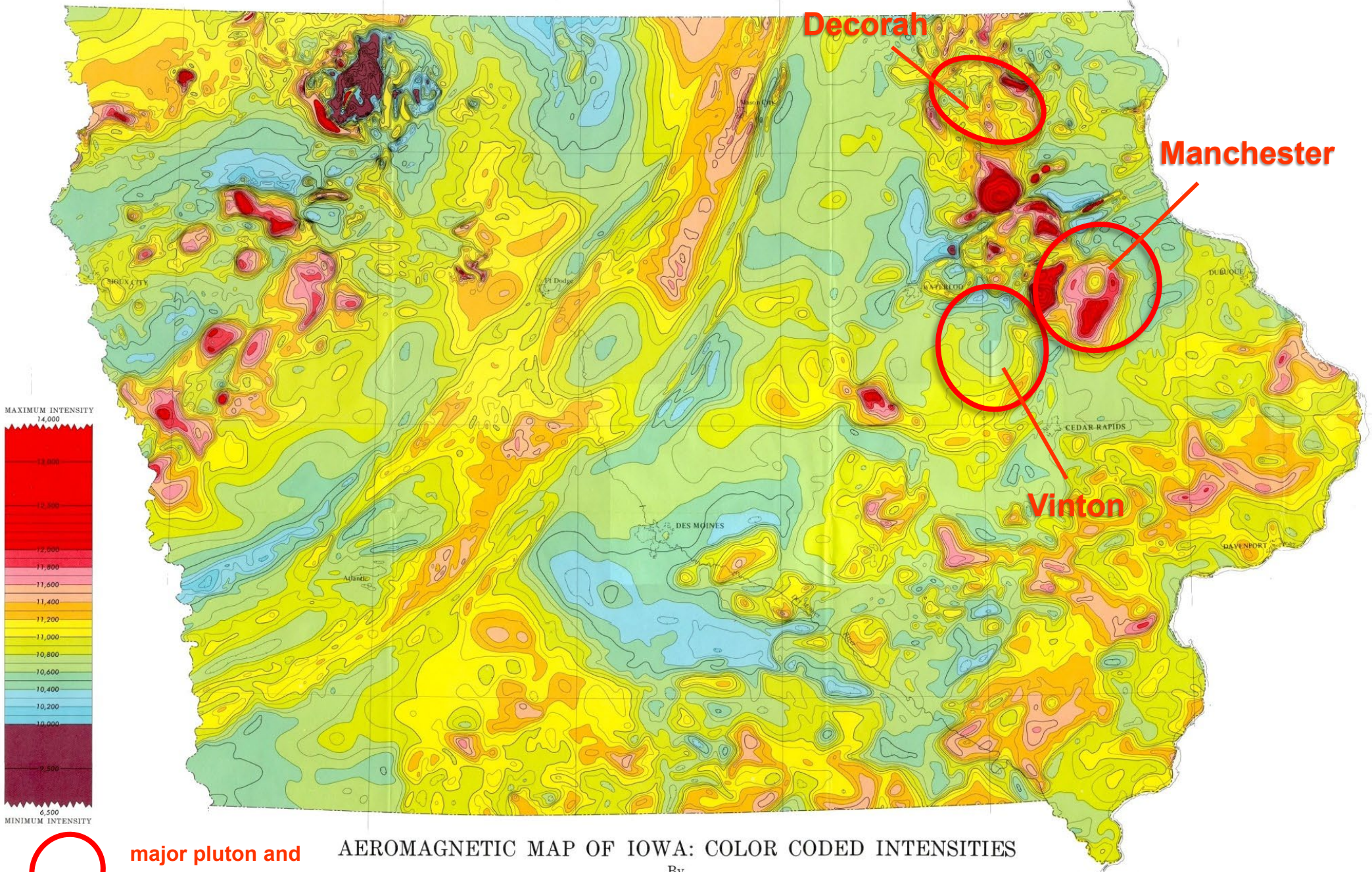


Precambrian Geology of Iowa and surrounding area

BOUGUER GRAVITY ANOMALY MAP OF IOWA



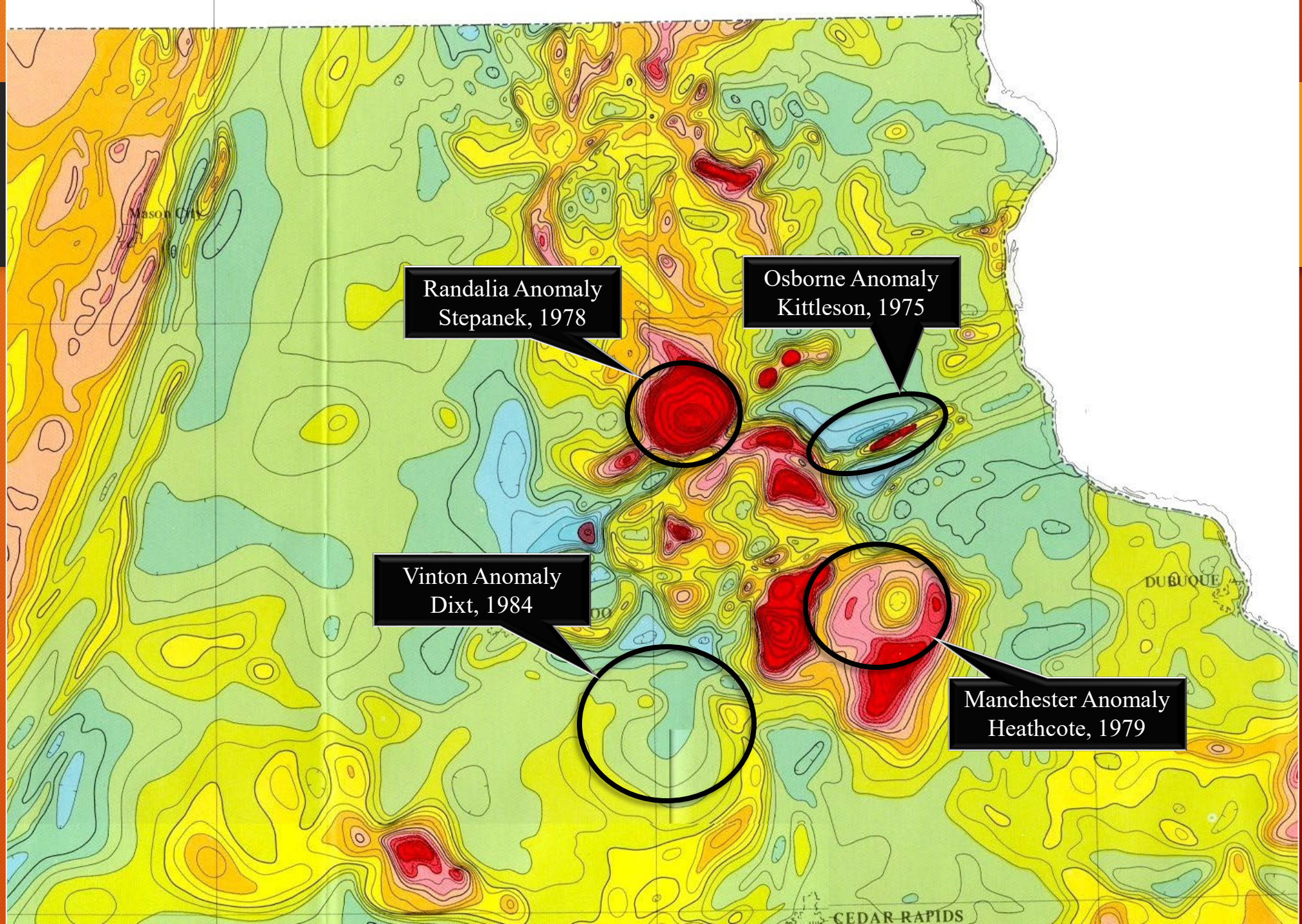
modified from Anderson (1981)



major pluton and name

AEROMAGNETIC MAP OF IOWA: COLOR CODED INTENSITIES

By
Isidore Zietz, Francis P. Gilbert, and John R. Kirby, Jr.
1976



Randalia Anomaly
Stepanek, 1978

Osborne Anomaly
Kittleson, 1975

Vinton Anomaly
Dixt, 1984

Manchester Anomaly
Heathcote, 1979

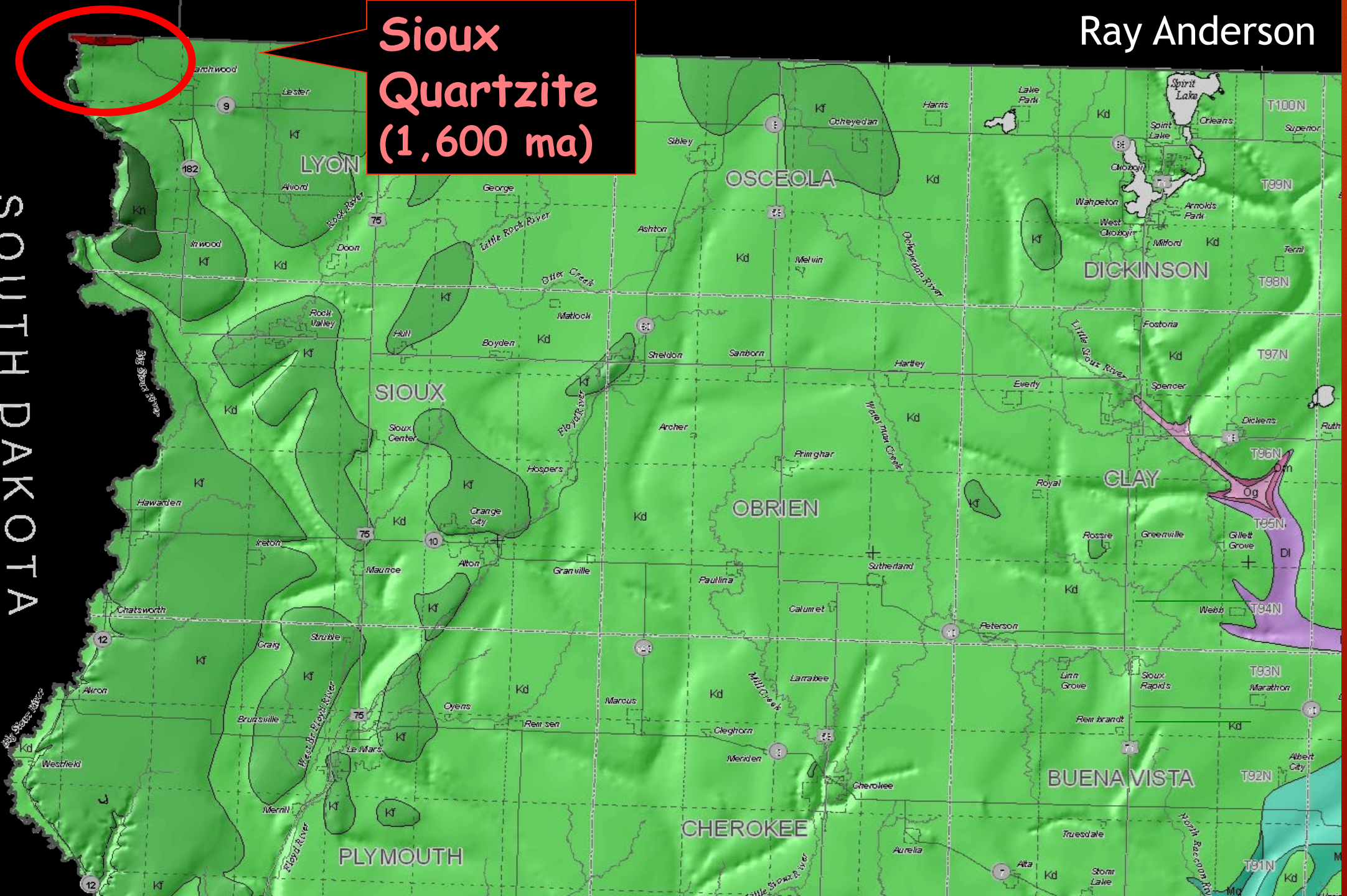
Precambrian - Major events

- 88% of the Earth's total history
- Crust forms (Continental and Oceanic)
 - Banded Iron Formation (BIF)
- Water on Earth
- Atmosphere begins to form
- Life begins single cell, then with photosynthesis to multicellular

Ray Anderson

Sioux
Quartzite
(1,600 ma)

SOUTH DAKOTA



Sioux Quartzite

- Gitchi Manitou State Preserve
 - 1969
- The rock is still quarried near Sioux Falls, SD
- Was mistakenly called Sioux Granite
- NOT part of an uplift rather the Sioux Ridge is likely a product of differential weathering



Sioux Quartzite

- Environment of Deposition?
 - Upper portion = tidal/shallow marine
 - Lower portion = fluvial/river
- The formation is up to 7,800ft thick
- Correlated with the Baraboo Quartzite
 - Occurs in eastern at great depths



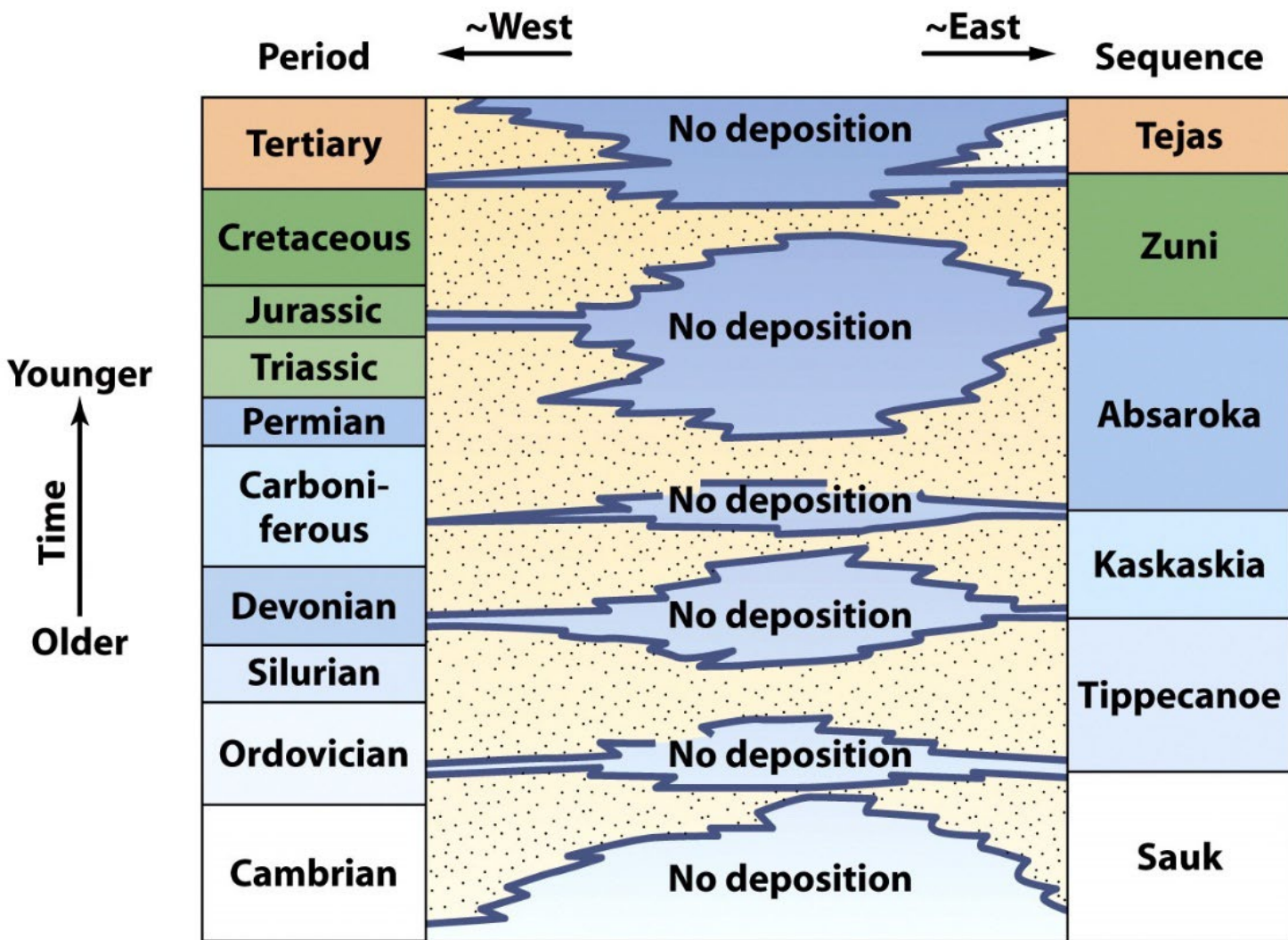
Federal building in Sioux Falls, SD

Pipestone

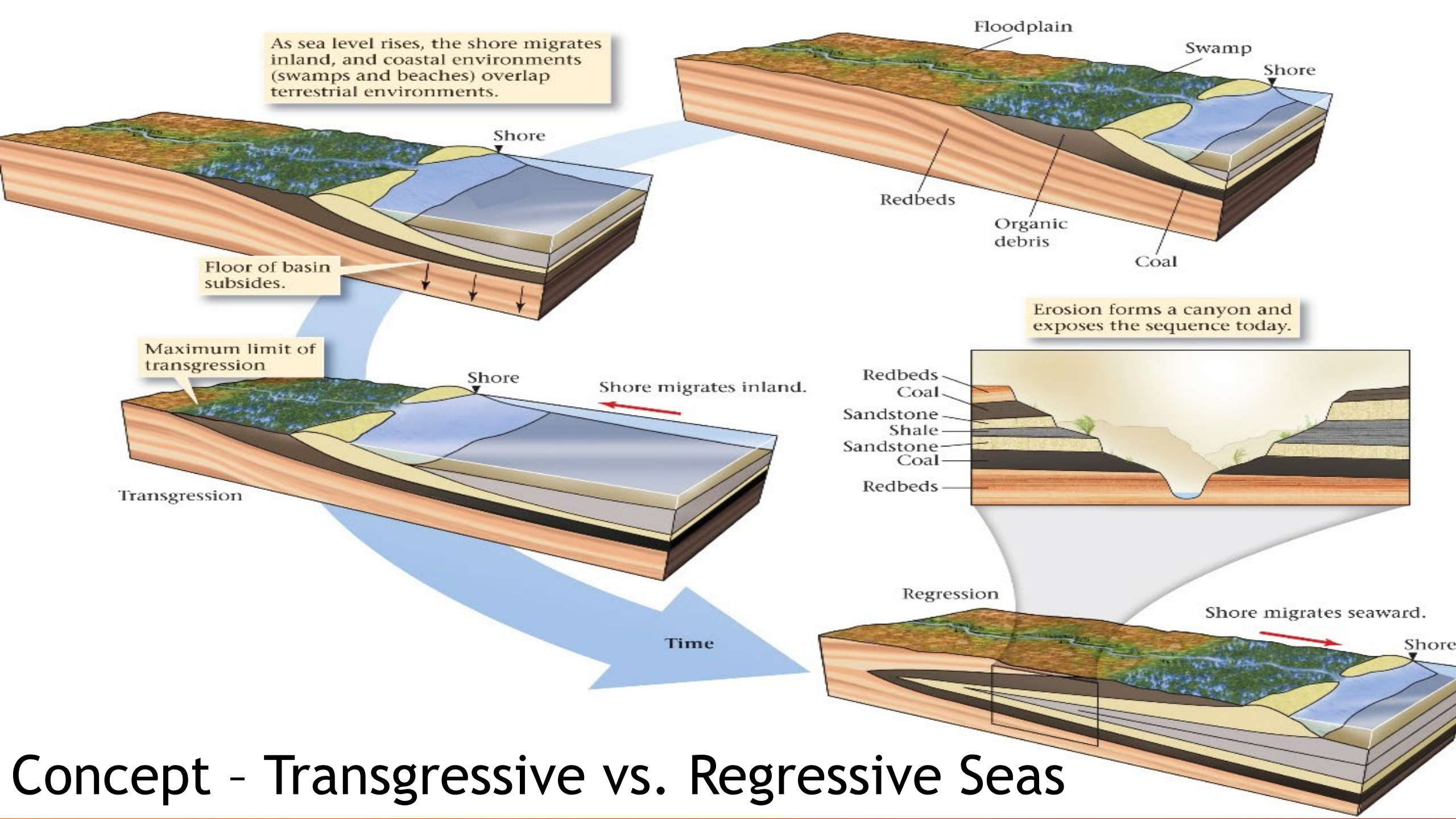
- Pipestone National Monument, MN
- Adjacent red to pink mudstones
 - Catlinite (after George Catlin, 1800s)
- Prized by Native Americans and traded throughout the Great Plains and Colombia River Basin



Iowa's Paleozoic

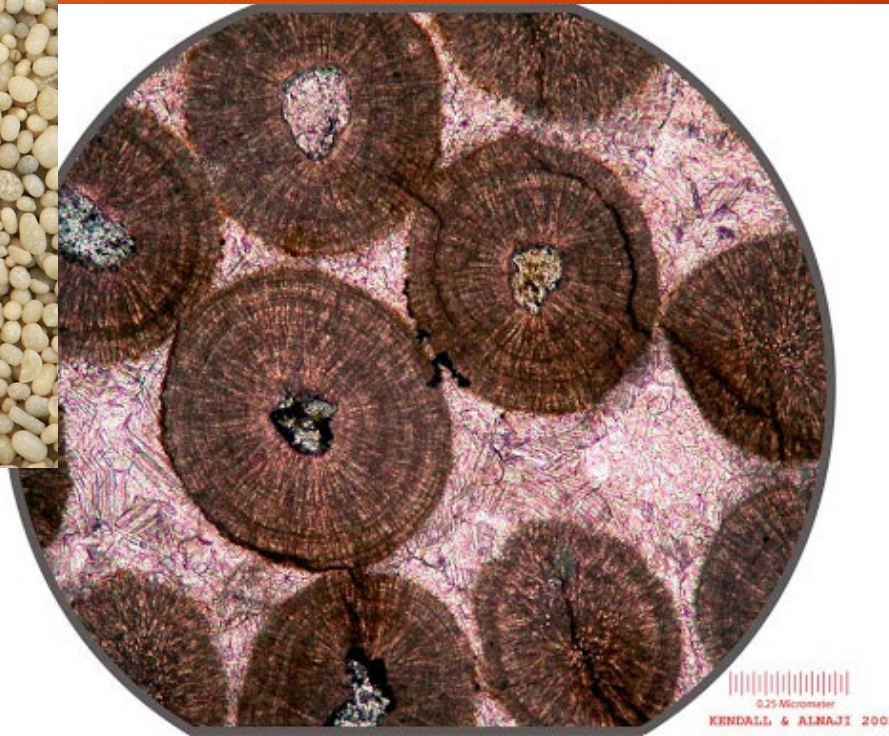


SEQUENCE	MES. ERA	PERMIAN TR. SYSTEM	EPOCH/SERIES/STAGE	WESTERN IOWA, EASTERN NEBRASKA, NORTHWESTERN MISSOURI	EASTERN IOWA, SOUTHEASTERN MINNESOTA		
ABSAROKA	MES. ERA	PERMIAN TR. SYSTEM	Chamberlain				
			Guadalupian				
			Leonardian				
			Wolfcampian	Wolfcamp Gp.			
			Virgilian	Virgil Gp.			
			Missourian	Lansing/Kare City/Pleco			
			PENN.	PERMIAN TR. SYSTEM	Desmoinesian	Desmoines Gp.	
					Alsean	Cherokee Gp.	Cherokee Ls. & Gp.
					Narrowwan		Fayetteville Fm.
					Cheslerian		
KASKASKIA	PALEOZOIC	MISS.	Maramecian	St. Genevieve/St. Louis/Spartan/Warsaw	St. Genevieve/St. Louis/Spartan/Warsaw		
			Osagean	Kassak/Burlington	Osage Fm.		
		DEVONIAN	DEVONIAN	Kinderhookian	Hampson Gp.	Kinderhook Fm.	
				Famennian	"Meads Mill" Sh.	Yellow Spring Gp.	
				Frasnian	"Lime Creek" - Cedar Valley unit	Lime Creek Sh.	
				Givetian	Wagonwheel	Cedar Valley	
				Eifelian		Wagonwheel	
						Eden	
TIPPECANOE	PALEOZOIC	SILUR.	Pridolian				
			Ludlovian				
		ORDOVICIAN	ORDOVICIAN	Wenlockian	Sil and II.	Gower Fm.	
				Llandoveryan		Spetch Grove Fm.	
				Richmondian	Modoc Fm.	Hopkinton/Blanding Fm.	
				Mazyvillian		St. Peter	
		CAMBRIAN	CAMBRIAN	Edenian	Gulian Gp.	Modoc Fm.	
				Sher./Kirk./Rockland.		Galen Gp.	
				Blackriveran	Black River Gp.	Franklin Fm.	
				Crazyan	Black River Fm.	Black River Fm.	
Whiterockian				St. Peter Gp.			
SAUK	CAMBRIAN	ORDOVICIAN		Shakopee Fm.	Shakopee Fm.		
				Onota Fm.	Onota Fm.		
		SILUR.	Trempealeuan	Jordan/St. Lawrence Fm.	Jordan/St. Lawrence		
			Franconian	Davis Fm.	Lime Rock/Francisco		
CAMBRIAN	CAMBRIAN	Dresbachian	Bonneville Fm.	Wagonwheel Fm.			
			Mt. Simon Gp.	Fish Clinton Fm.			



Concept - Transgressive vs. Regressive Seas

Importance of oolites

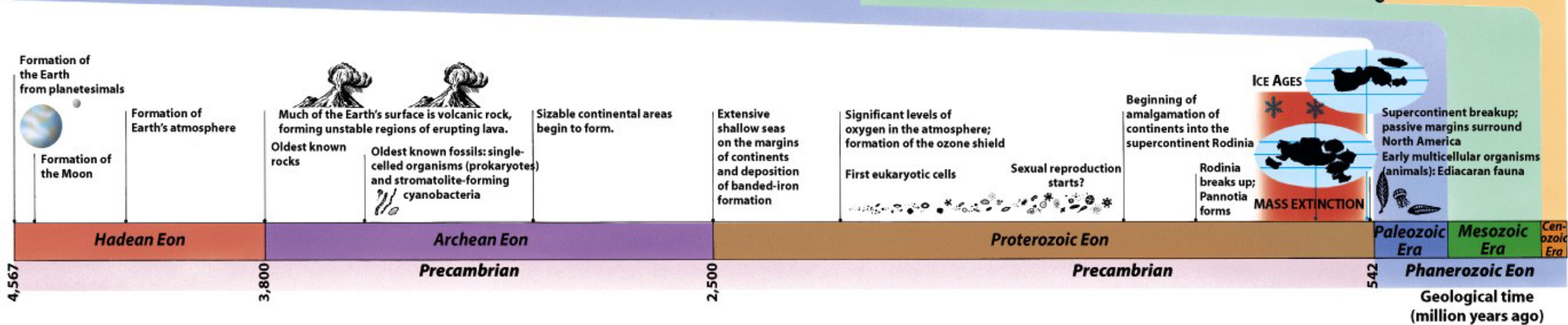
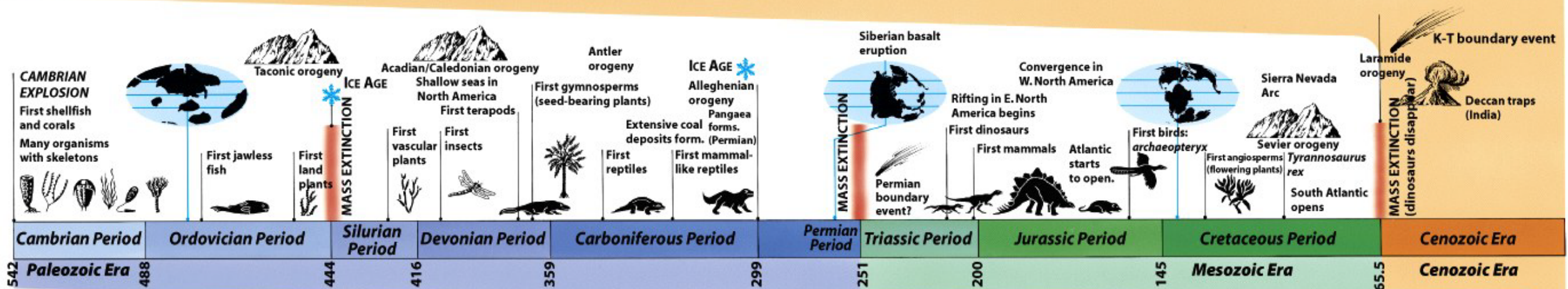
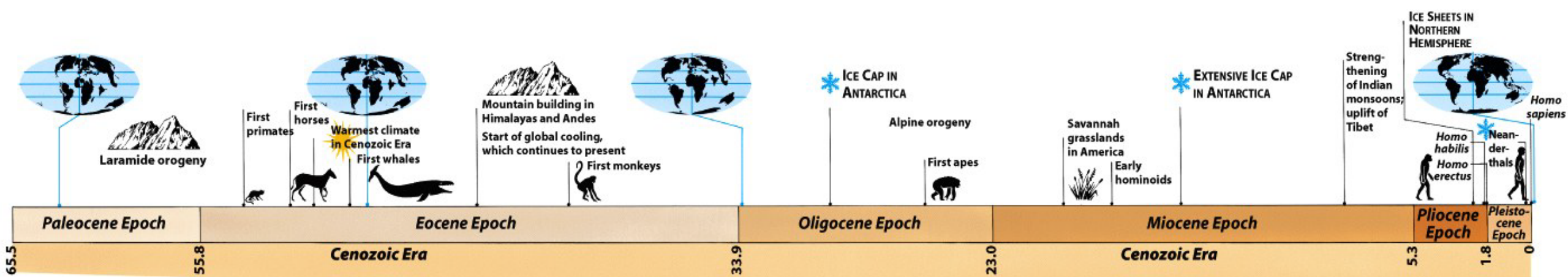


- Ooids are sand-sized grains of calcite or aragonite
- They indicate depositional environments
 - Shallow water
 - Agitated water
 - Warm water
 - That leads to decreases CO_2 and increases in Ca^{2+} and ppt. of spherical CaCO_3

Cambrian - Sandy Marine Shelves & Shorelines

485 Ma
to
541 Ma

- The Cambrian is generally known as a period for the Explosion of Life and for a dramatic increase in available/atmospheric O₂
- The early to mid-Cambrian saw massive periods of weathering/erosion and as a product there is a large unconformity until the late Cambrian in Iowa
- During the Late Cambrian, shallow seas encroached upon Iowa and reworked the eroded (Precambrian & Early Cambrian) sediments including resistant quartz, feldspar, clay minerals, and trace amounts of zircon, tourmaline and garnet.

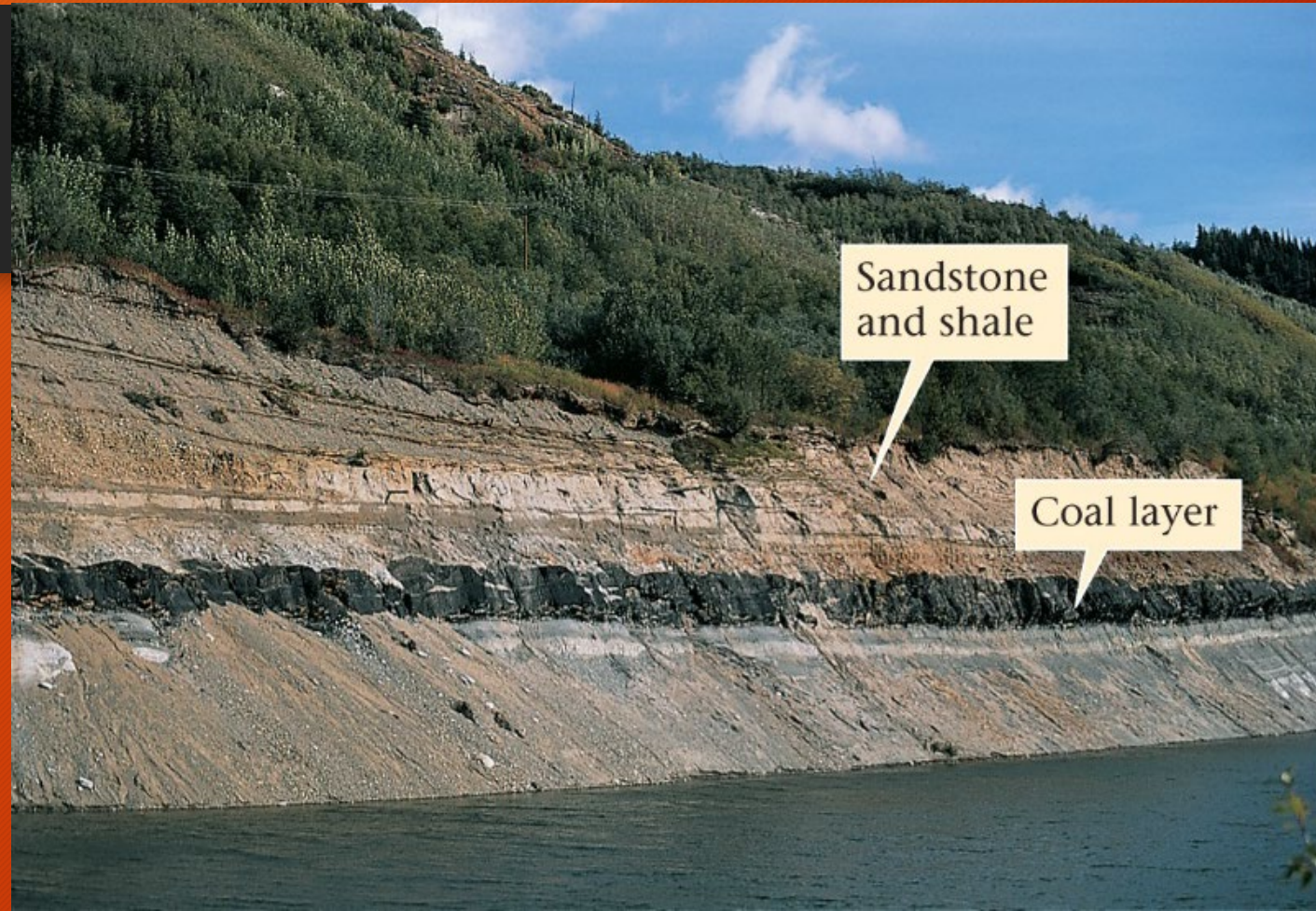


Late Cambrian Sandstone

- Throughout the Midwest there are numerous sandstone formations that are mature:
 - A. Physically
 - Well rounded
 - Well sorted
 - B. Chemically
 - Mostly quartz
 - Some areas rich in feldspar too

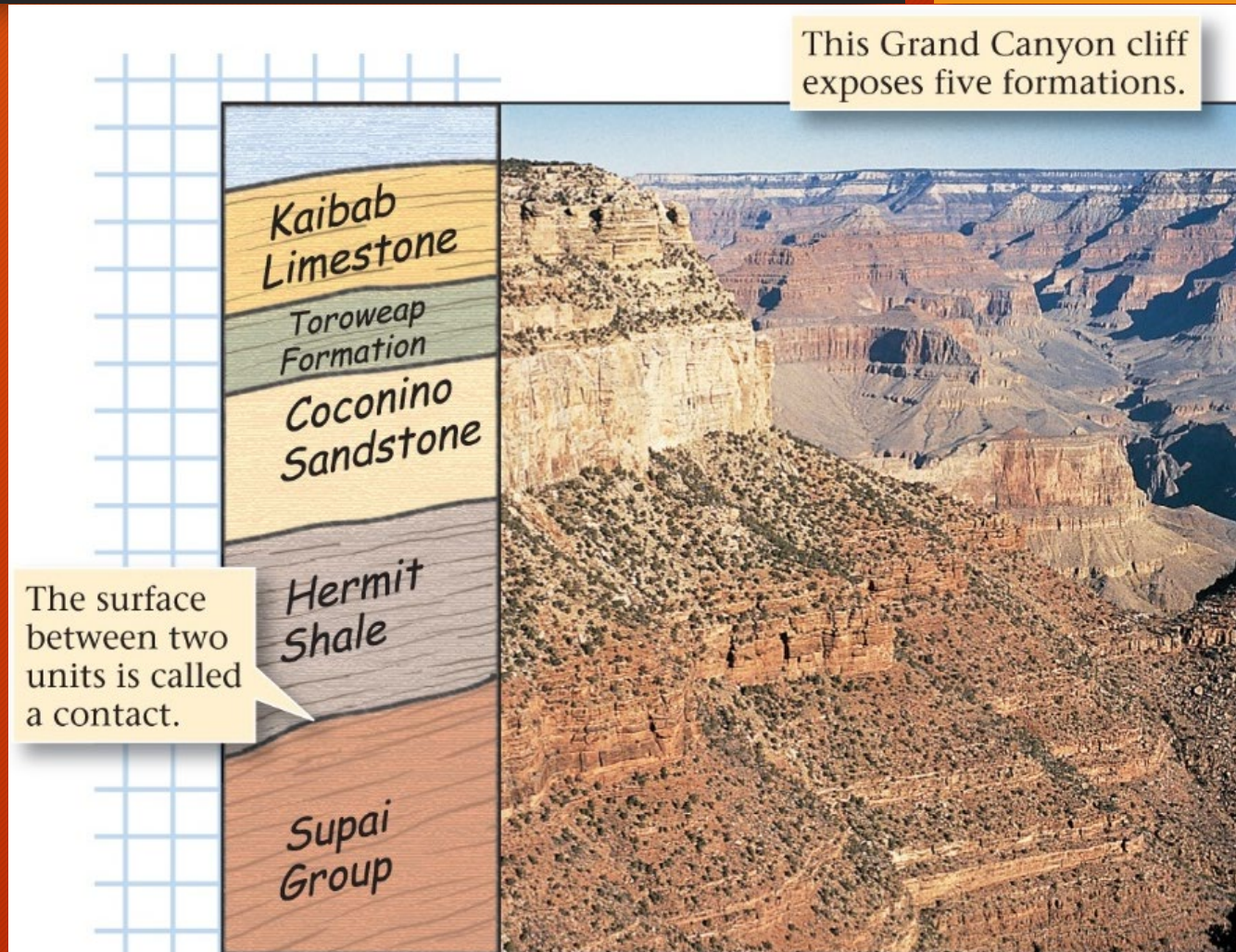
Geologic *Formations*

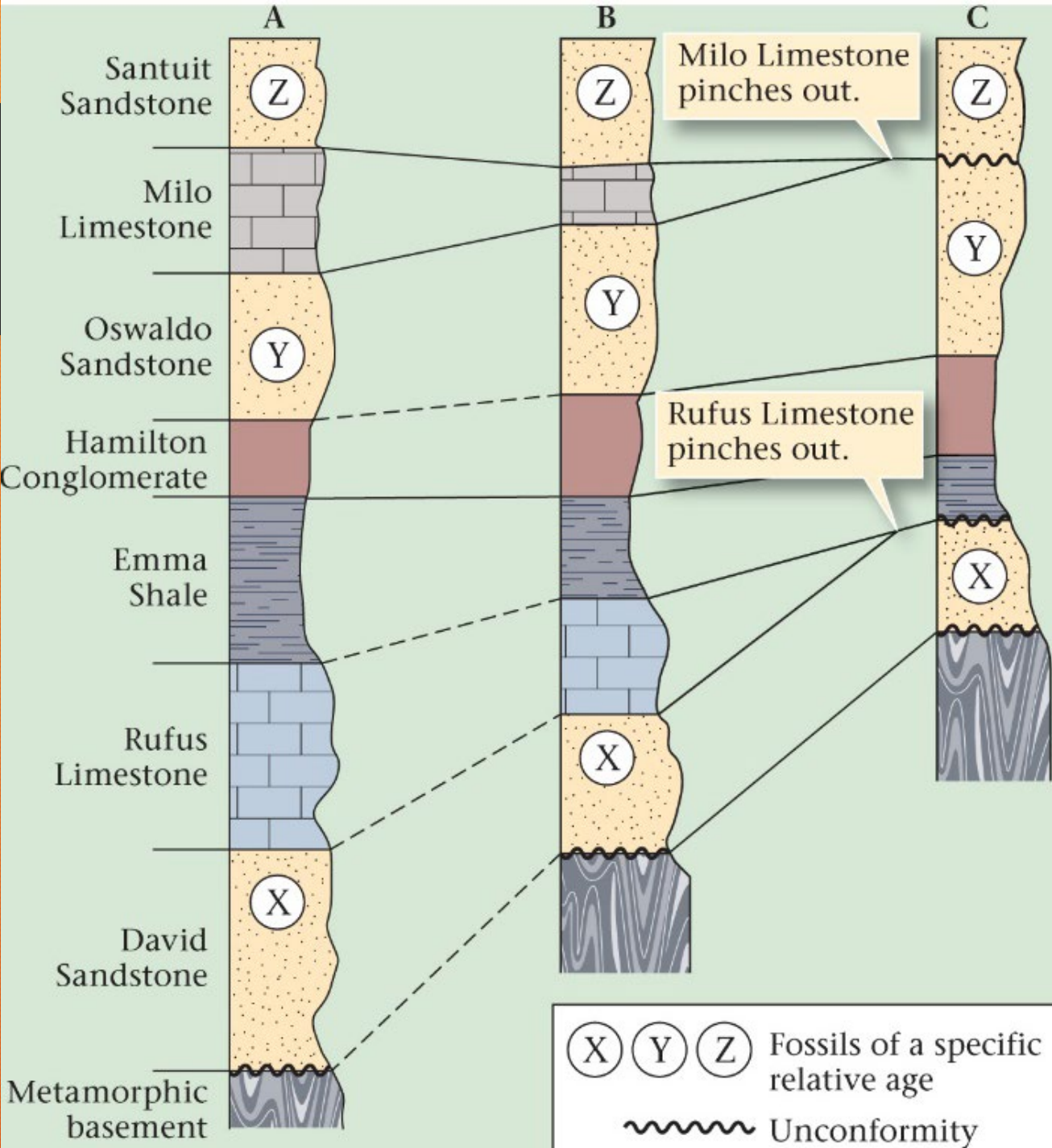
- A body/layer of rock that consists dominantly of a certain lithologic rock type
- Maybe combined into *Groups*
- Or maybe divided into *Members*



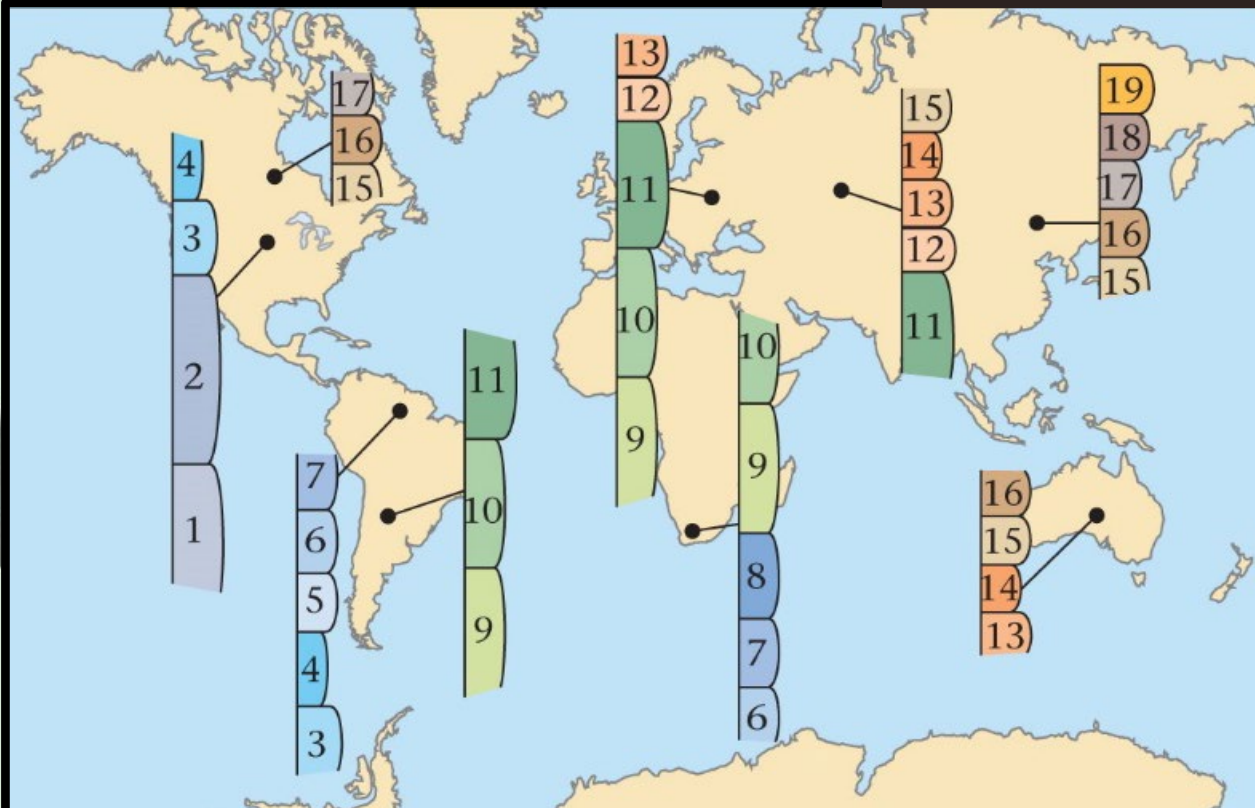
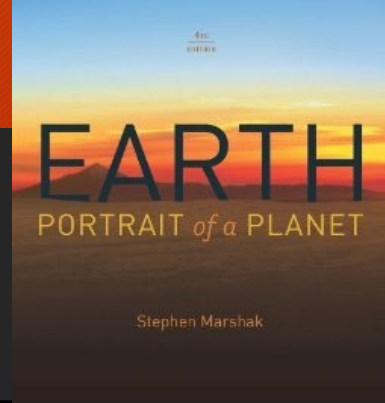
Stratigraphy - The science of rock layers

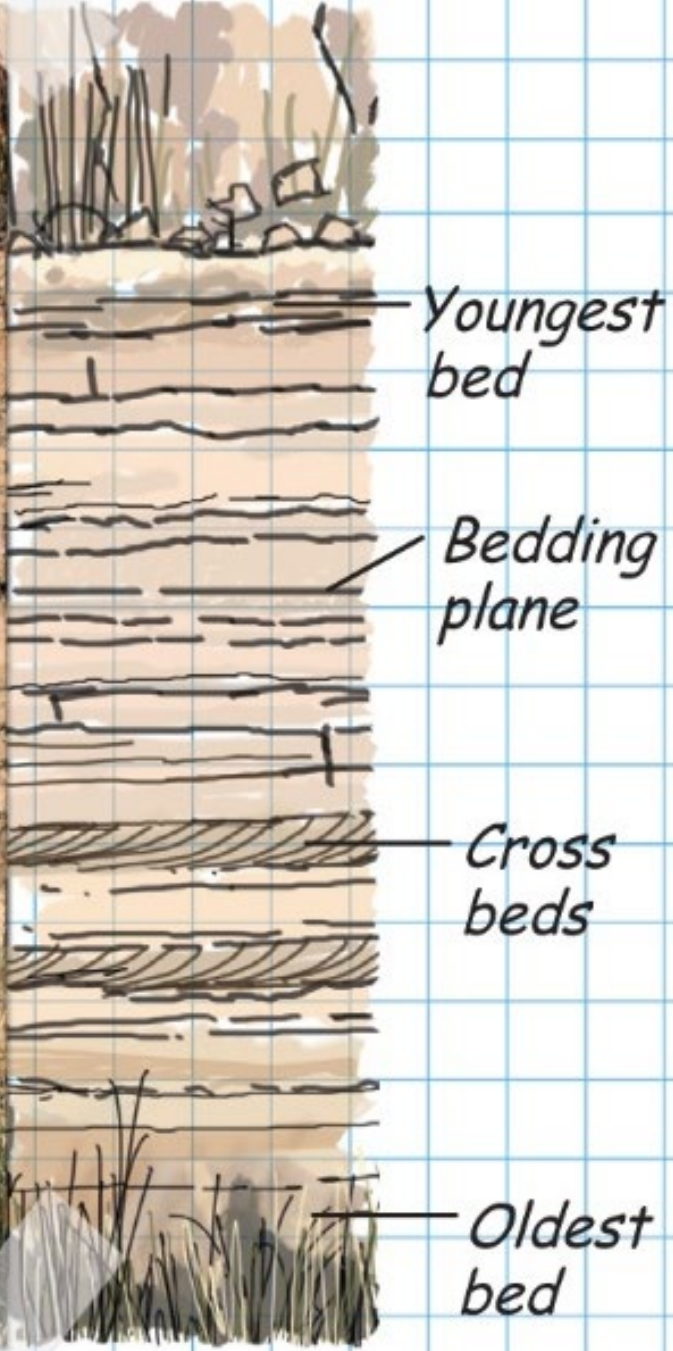
- Concerned with all characters and properties (physical, chemical and/or biological)
- Enables geologists to trace rock formations from one place to another
- Helps geologists to interpret modes of origin and history



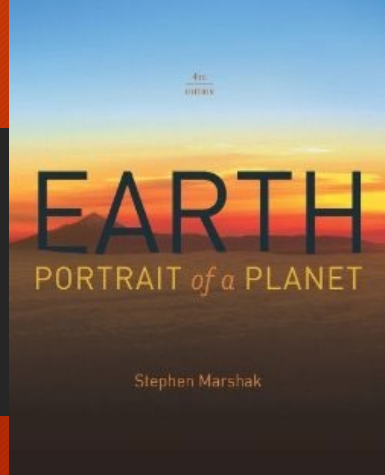


Correlation





What a Geologist Sees



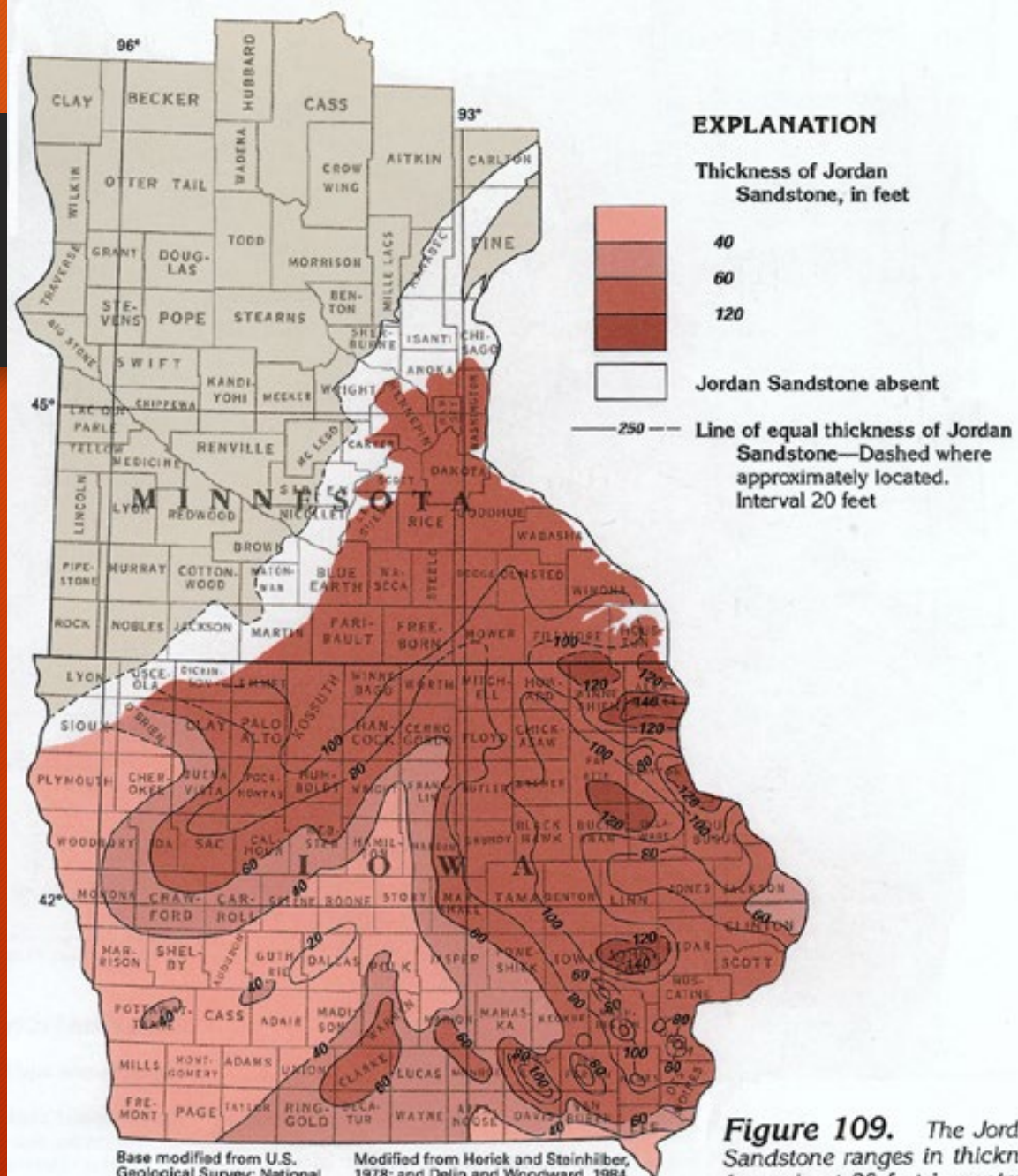
Relative dating Superposition

The Jordan Sandstone

- Some layers are cemented with dolomite
- Formed on a shallow marine shelf and shoreline
- High porosity and moderate permeability
 - Serves as one of the Iowa's best groundwater/aquifers



Jordan Fm. Thickness



Base modified from U.S. Geological Survey; National Atlas, 1:7,500,000, 1970

Modified from Horick and Stainhiller, 1978; and Delin and Woodward, 1984

SCALE 1:5,000,000

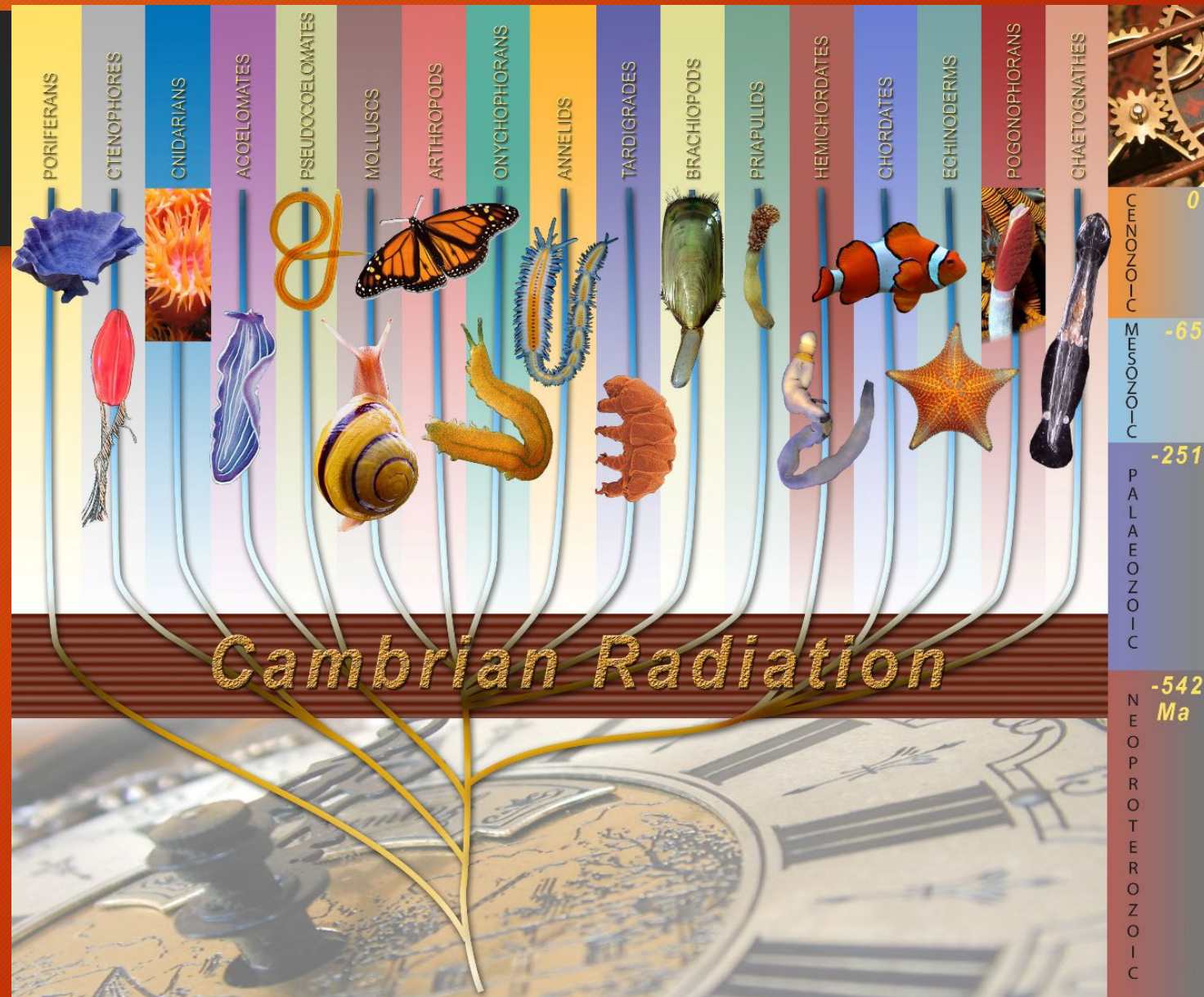
0 50 MILES

0 50 KILOMETERS

Figure 109. The Jordan Sandstone ranges in thickness from about 20 feet in central Iowa to about 140 feet in northeastern and east-central Iowa.

Cambrian Life

- The age of the Trilobites
- Trilobites and brachiopods are abundant in this period, but not in Iowa.
- Why???
- Iowa's Cambrian record is dominated by SANDY near shore transition environments.





Opabinia

- Five stalked eyes (likely for detecting light/dark and predators) and a backward-facing mouth beneath its head
- Initially hard to classify, *Opabinia* is now recognized as a stem-group arthropod related to modern tardigrades and radiodonts



Wiwaxia

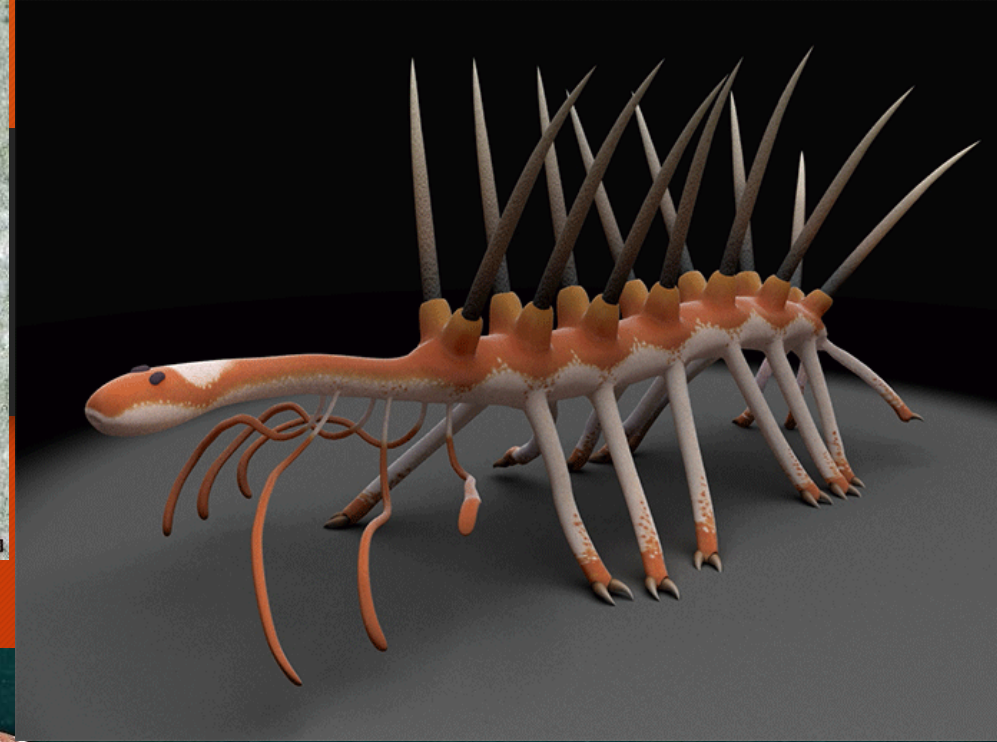
- Oval in shape, 2-5 cm in length, with two rows of tall, dorsal spines used for defense and smaller scaly sclerites covering its body.
- One of the early multicellular organisms that appeared during the Cambrian explosion and is closely affiliated with early mollusks, although its exact position is still debated.



Hallucigenia



- Detailed 2015 studies identified a simple, elongated head featuring a pair of small eyes and a mouth surrounded by a ring of teeth.
- A key lobopodian, providing insight into the rapid diversification of animal body plans during the Cambrian explosion.



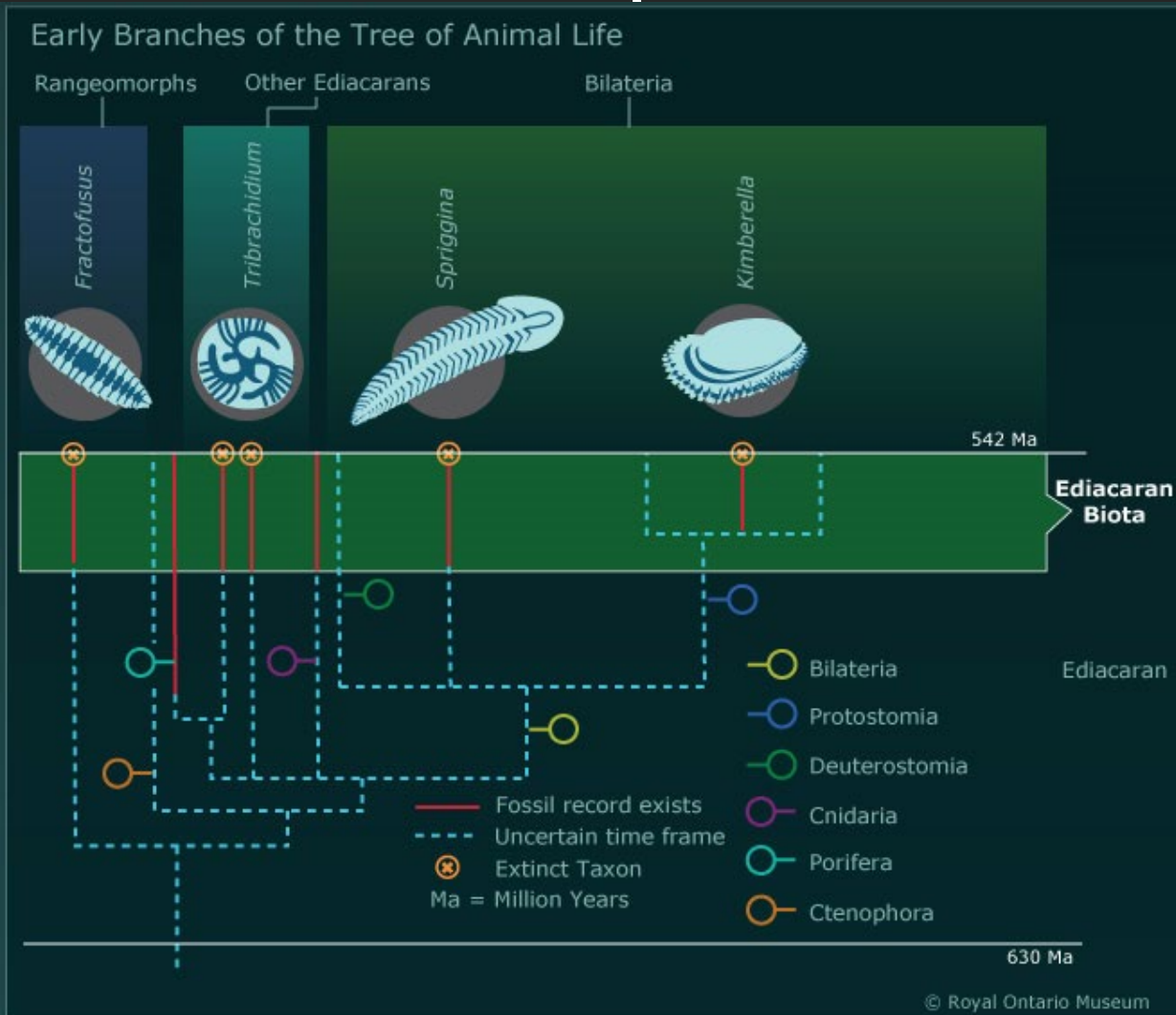
Geo-Factors leading to the Explosion of Life

- Increase in dissolved and atmospheric O_2
- Geologic and Biologic Time nearly 3Ga and 2Ga of photosynthesis
- Increase in atmospheric ozone O_3
- Snowball Earth/extinctions /genetic bottlenecks
- Increased oceanic Ca^{+2} made it easier for shell creation
 - Erosion of the Transgondwanan Super-mountain
- Life finds away...

Bio-Factors or increase in disparity & diversity, but not an explosion

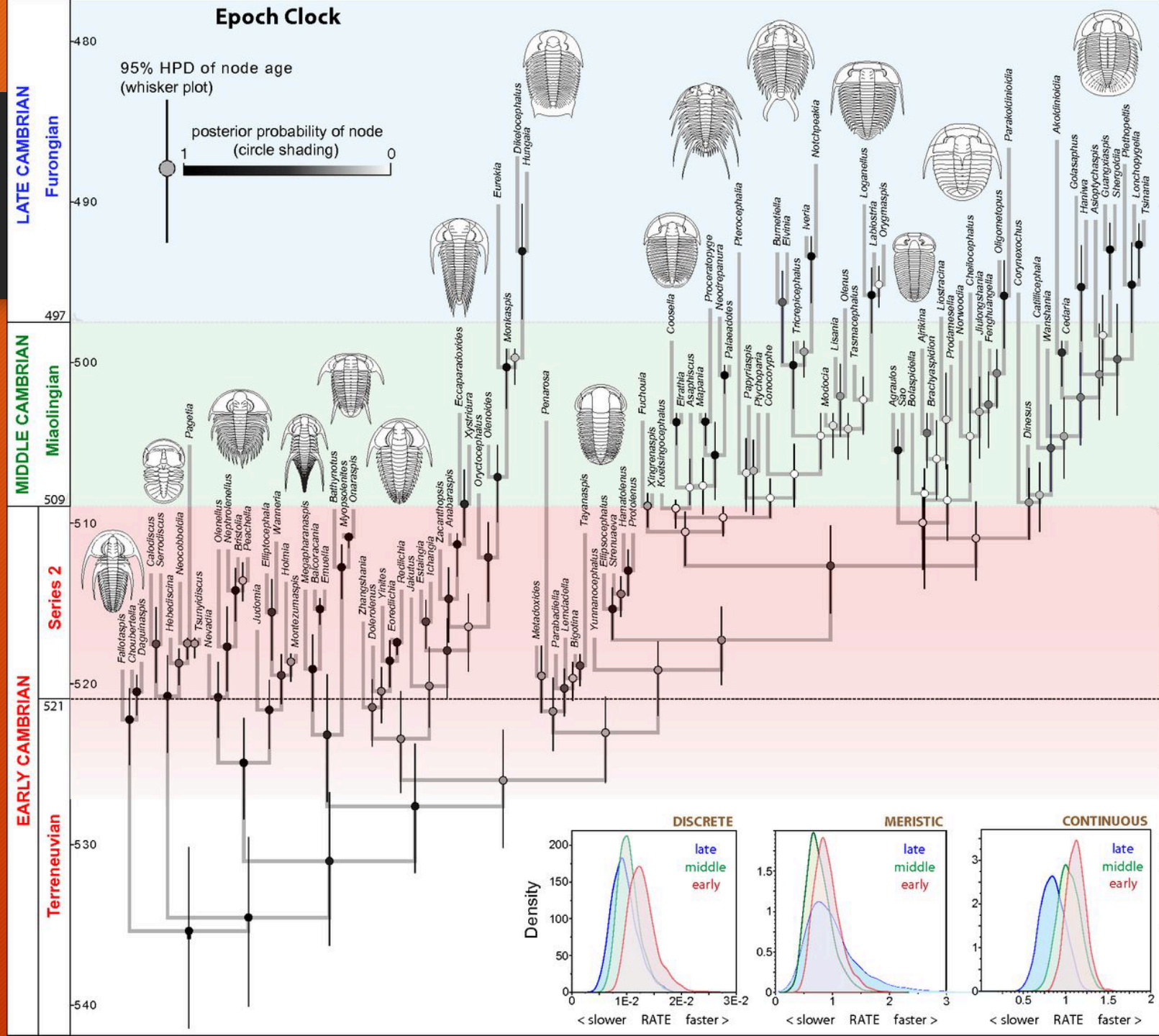
Coevolution - opportunistic adaptability

- Ediacaran sea floor
- Water column



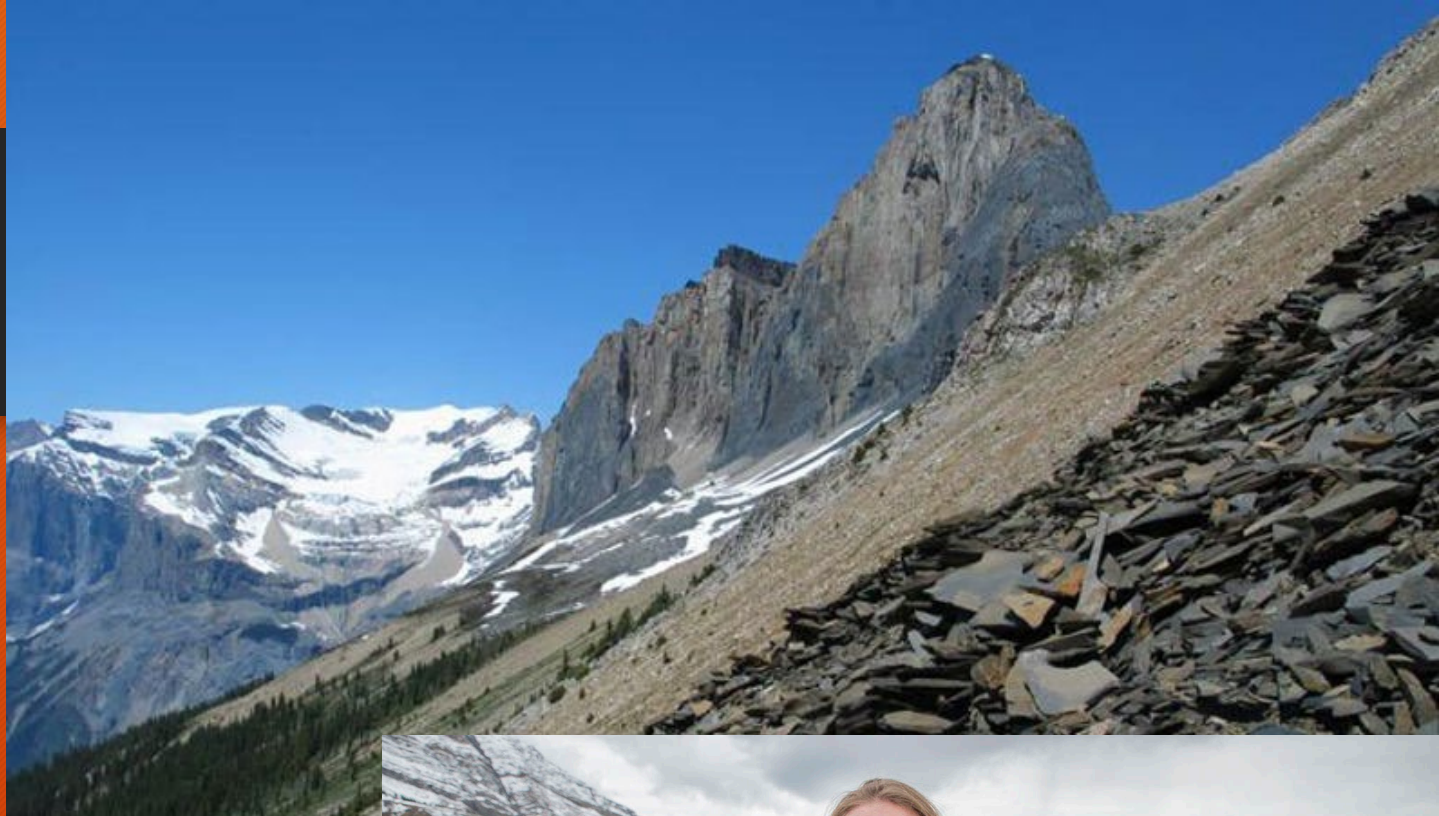
Trilobites constrain the Cambrian Explosion

- Trilobites start and nearly end within the Cambrian.
- Major but Not complete extension toward the end

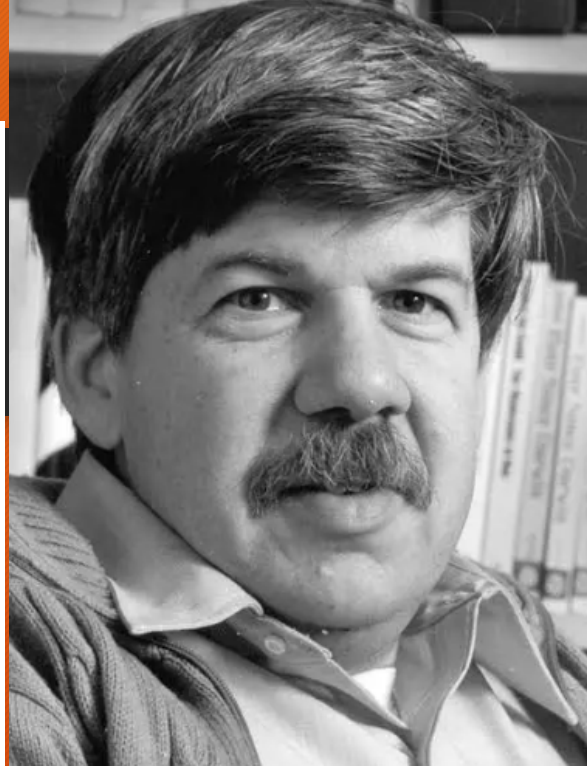
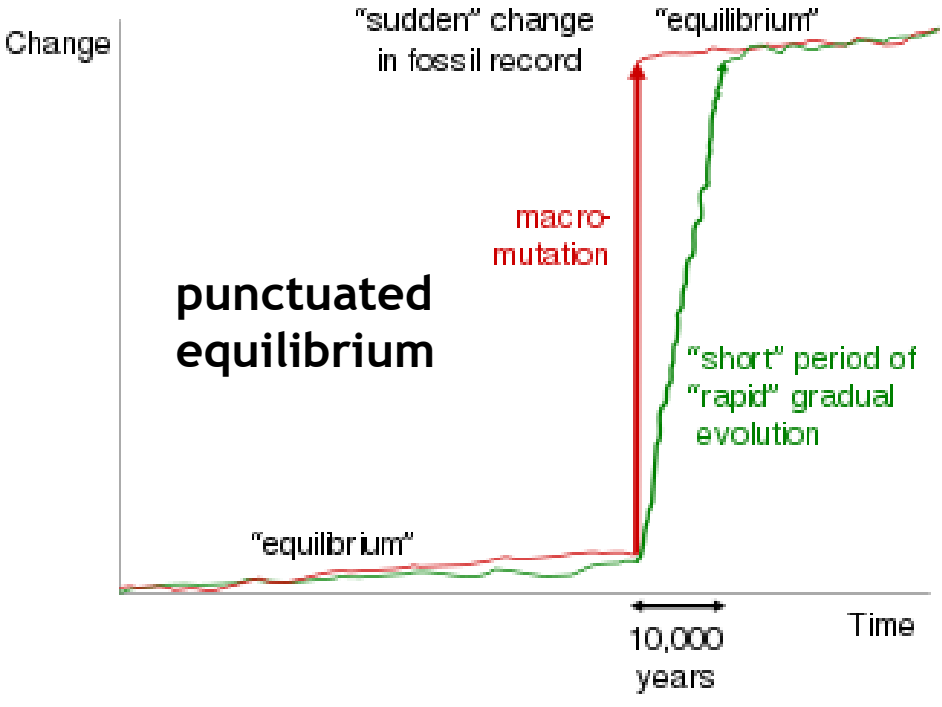


Burgess Shale

- Canadian Rockies, British Columbia
- Charles Walcott, 1909



Stephen Jay Gould

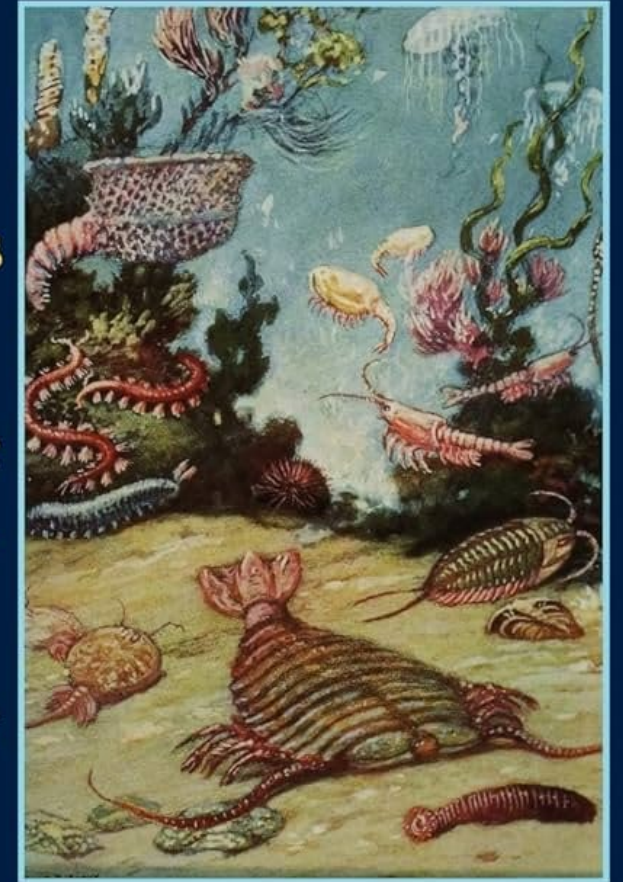


"Life, human life is a mere occurrence of time. I say this not to be little our existence, but rather to emphasize the miracle, that we are here at all."

-
- Stephan J. Gould (Lecture to the University of Wisconsin, Superior, 1998)

Wonderful Life

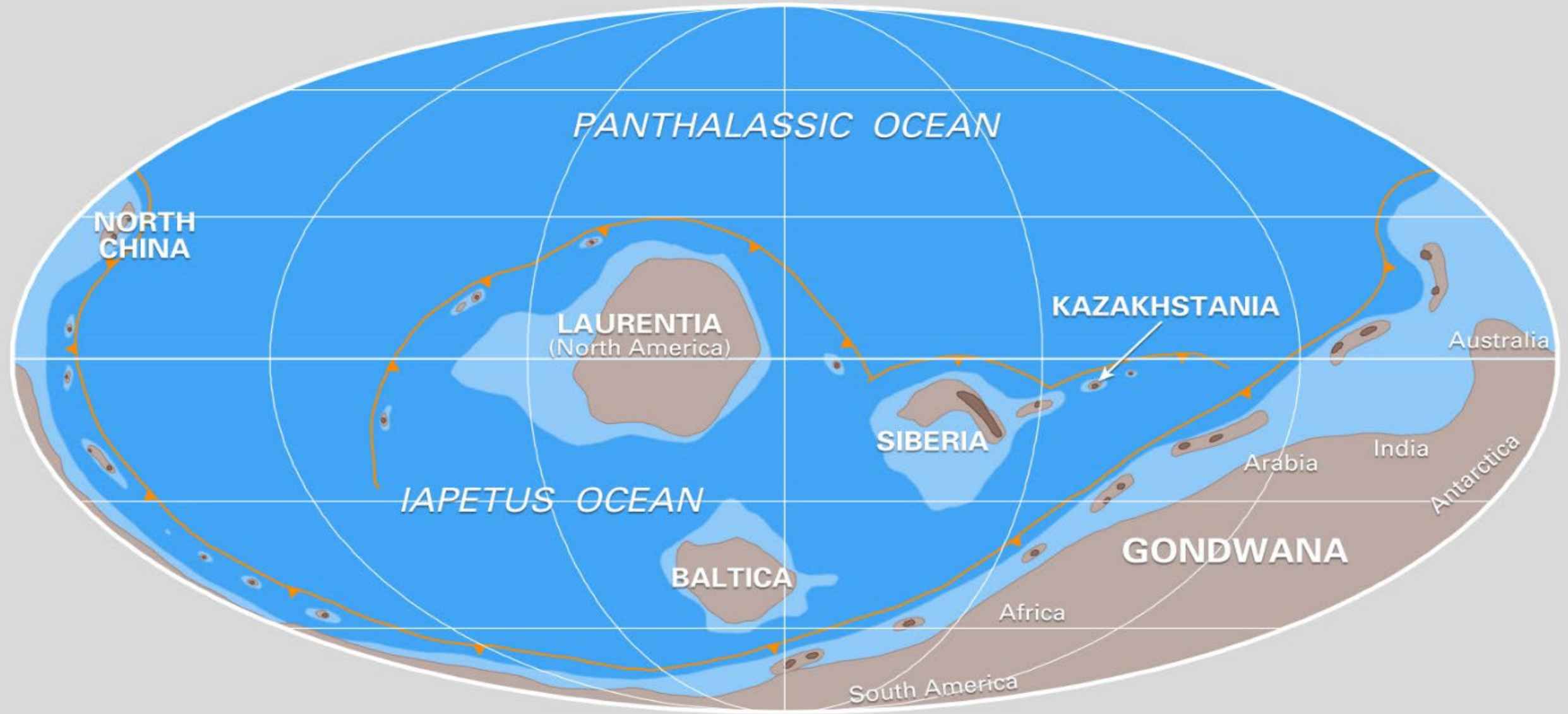
The
Burgess
Shale
and the
Nature
of
History



STEPHEN JAY GOULD

Late Cambrian 514 million years ago

<http://www.scotese.com/>



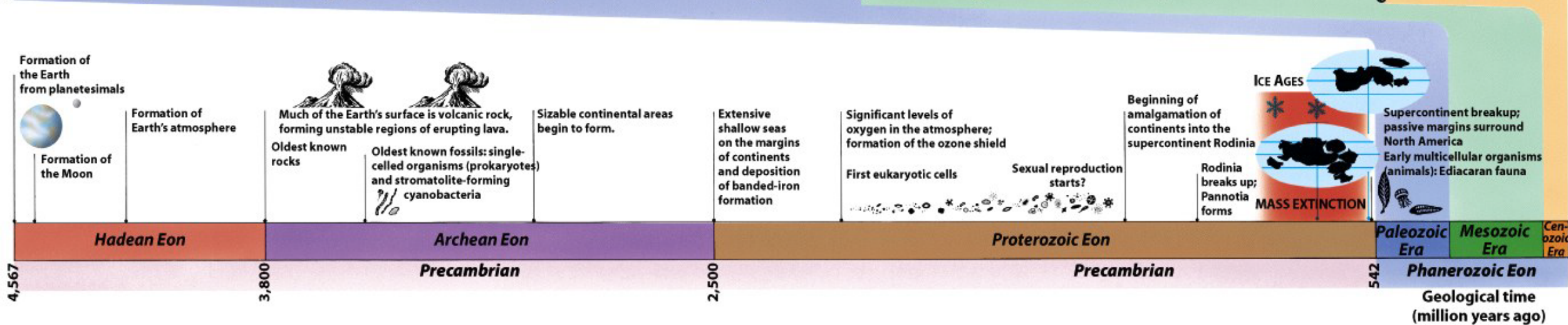
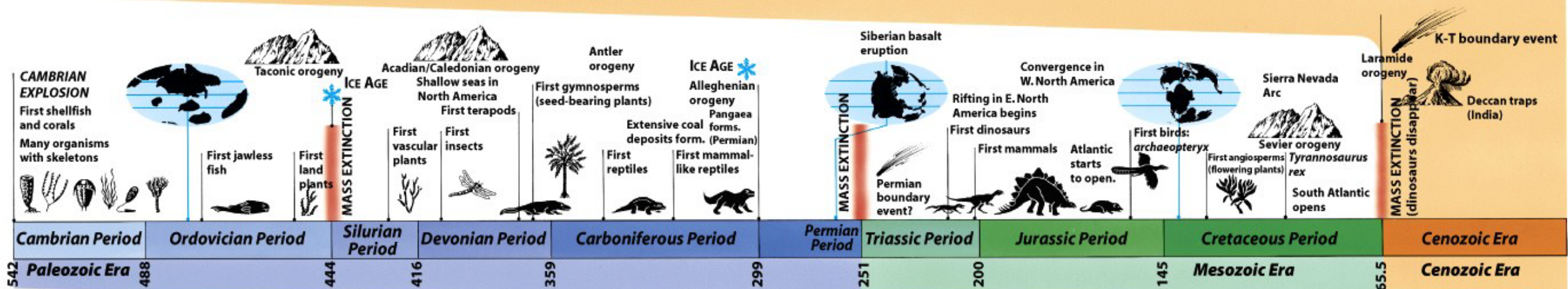
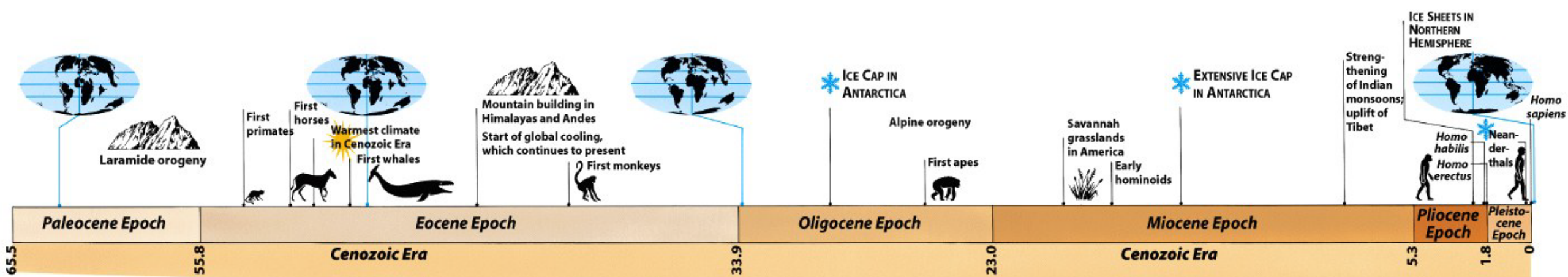
Legend for the map:

- Mountains
- Land
- Shallow seas
- Deep ocean basins
- Subduction zone (triangles point in the direction of subduction)

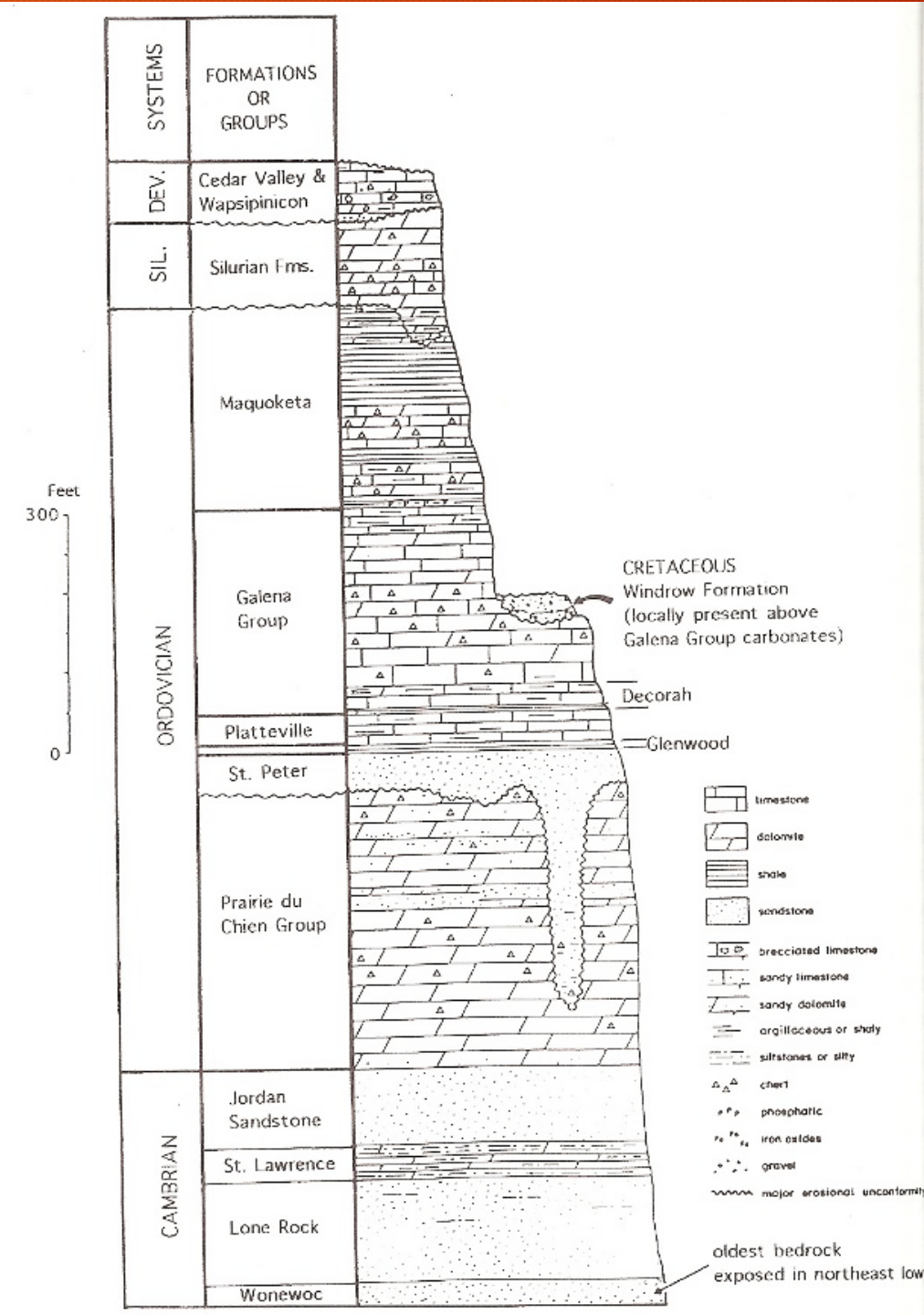
Ordovician - Warm, Shallow Seas

443 Ma
to
485 Ma

- Early Ordovician - Again on the edge of a shallow sea depositing carbonate, sandy carbonate, and quartz sandstones (Prairie du Chien Group) before another series of weathering and erosion!
- Mid-Ordovician - Major sea transgression changed a sandy shallow sea to carbonate shelf. Ash layers appear in the Decorah and Dunleith Formations.
- Late Ordovician - Increasingly muddy depositional environments forming the carbonate-rich shale layers (e.g. the Maquoketa Shale).
- Towards the end of the Ordovician the seas regress and weathering and erosion begin again, creating an ???

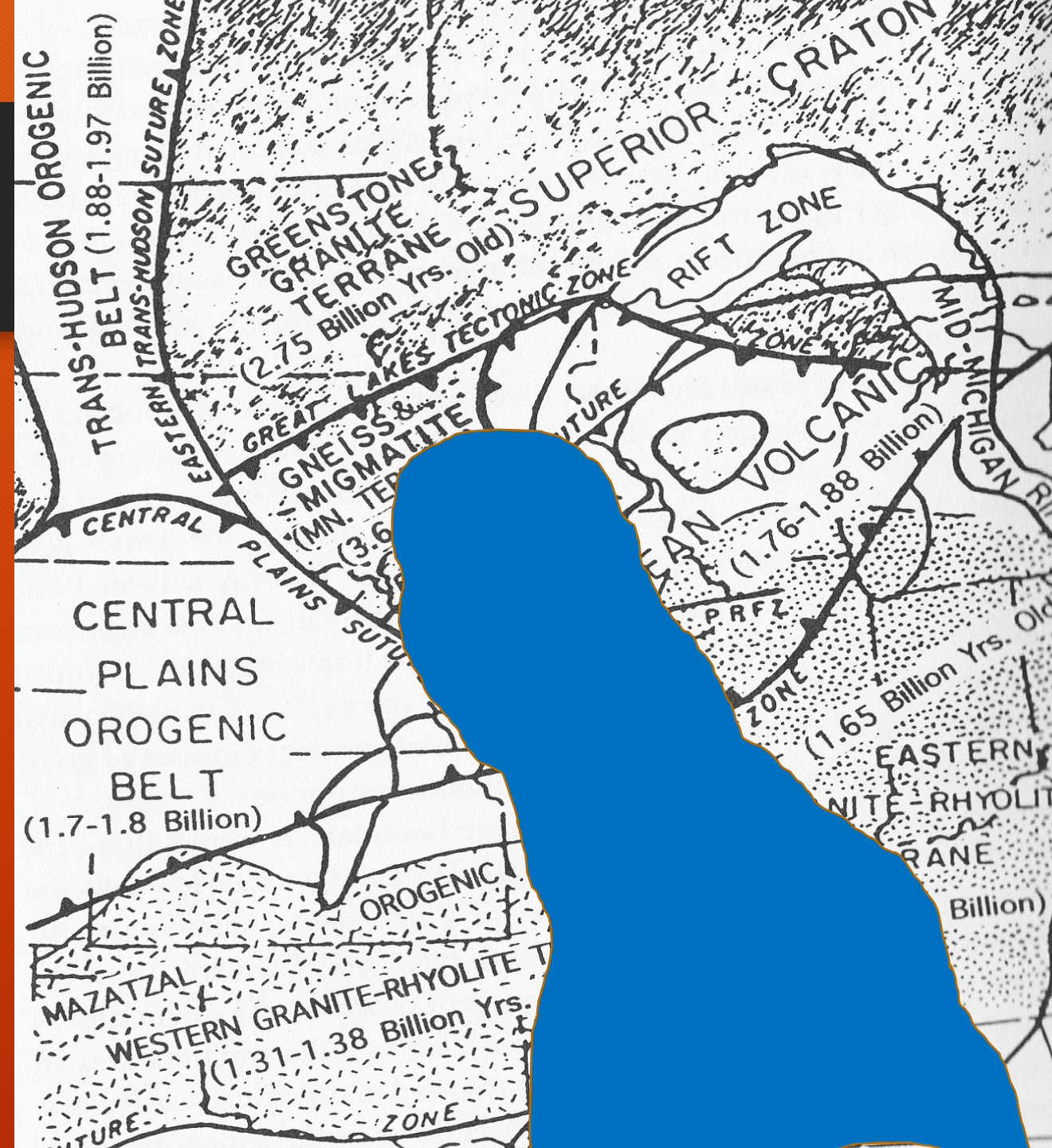


Ordovician Stratigraphy



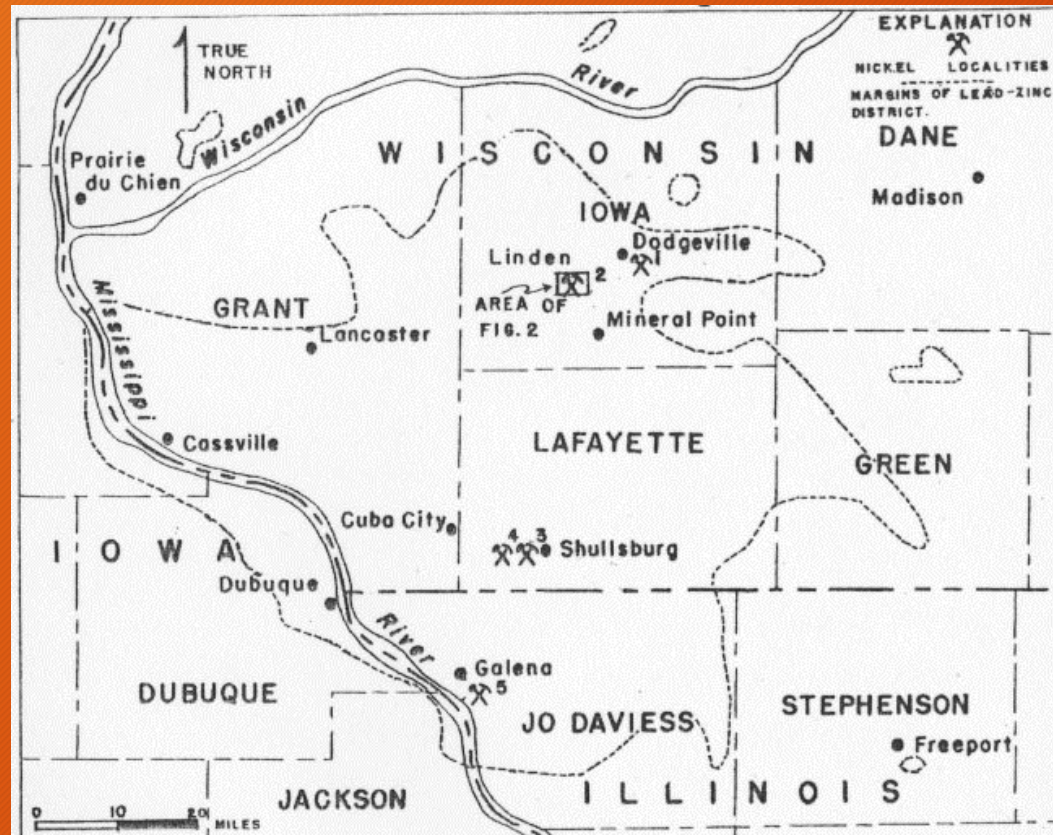
St. Peter Formation

- Quartz Sandstone (super mature)
 - But, In NW Iowa the St. Peter contains a lot of shale from the then exposed Transcontinental Arch
- Well exposed in Pikes Peak St. Park
- An important economic resources for glass and fracking
- 1960's served as a fall out shelter with supplies to meet the needs of 44,000 residents for two weeks

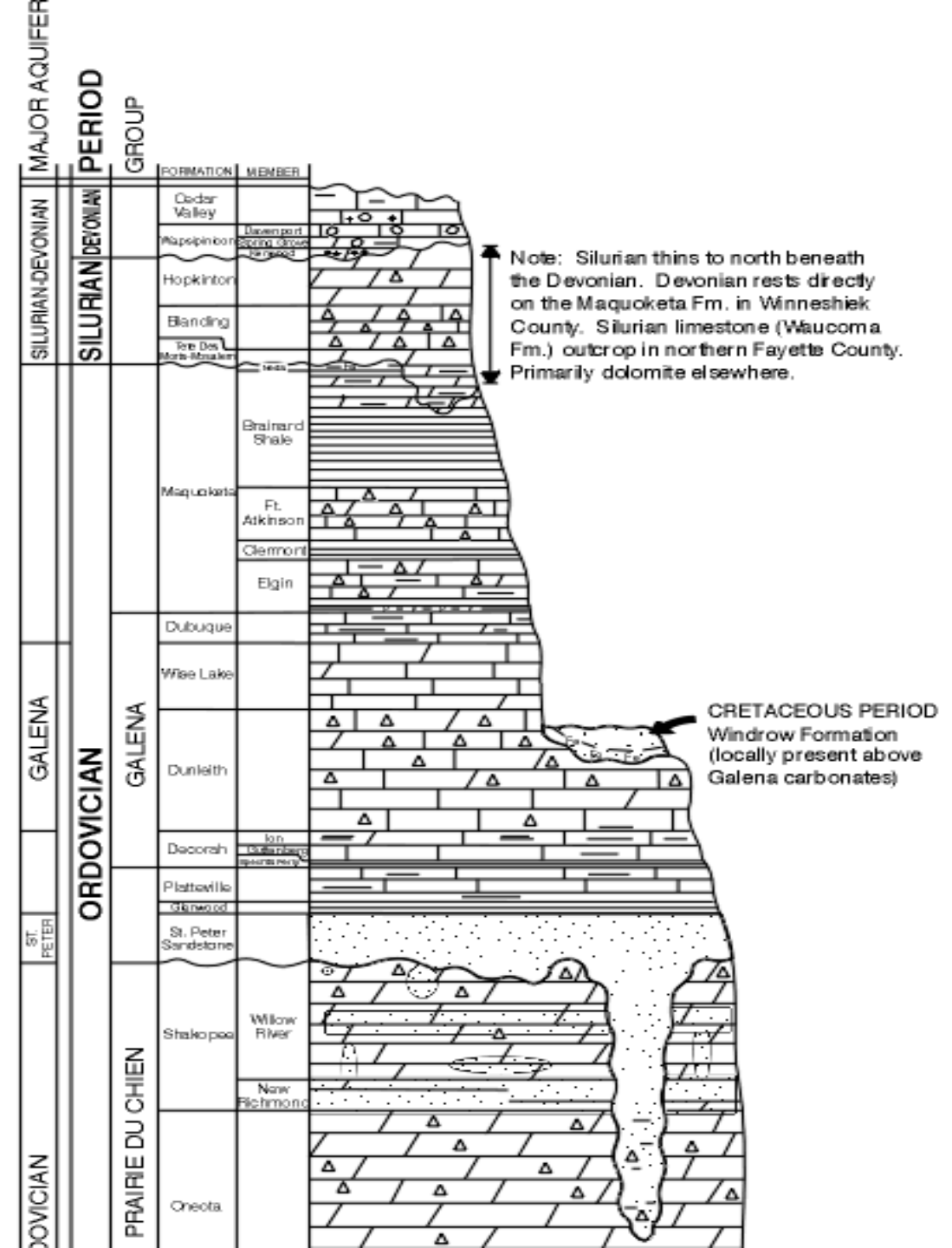


Galena Group

- Dunleith, Wise Lake, and Dubuque Formations

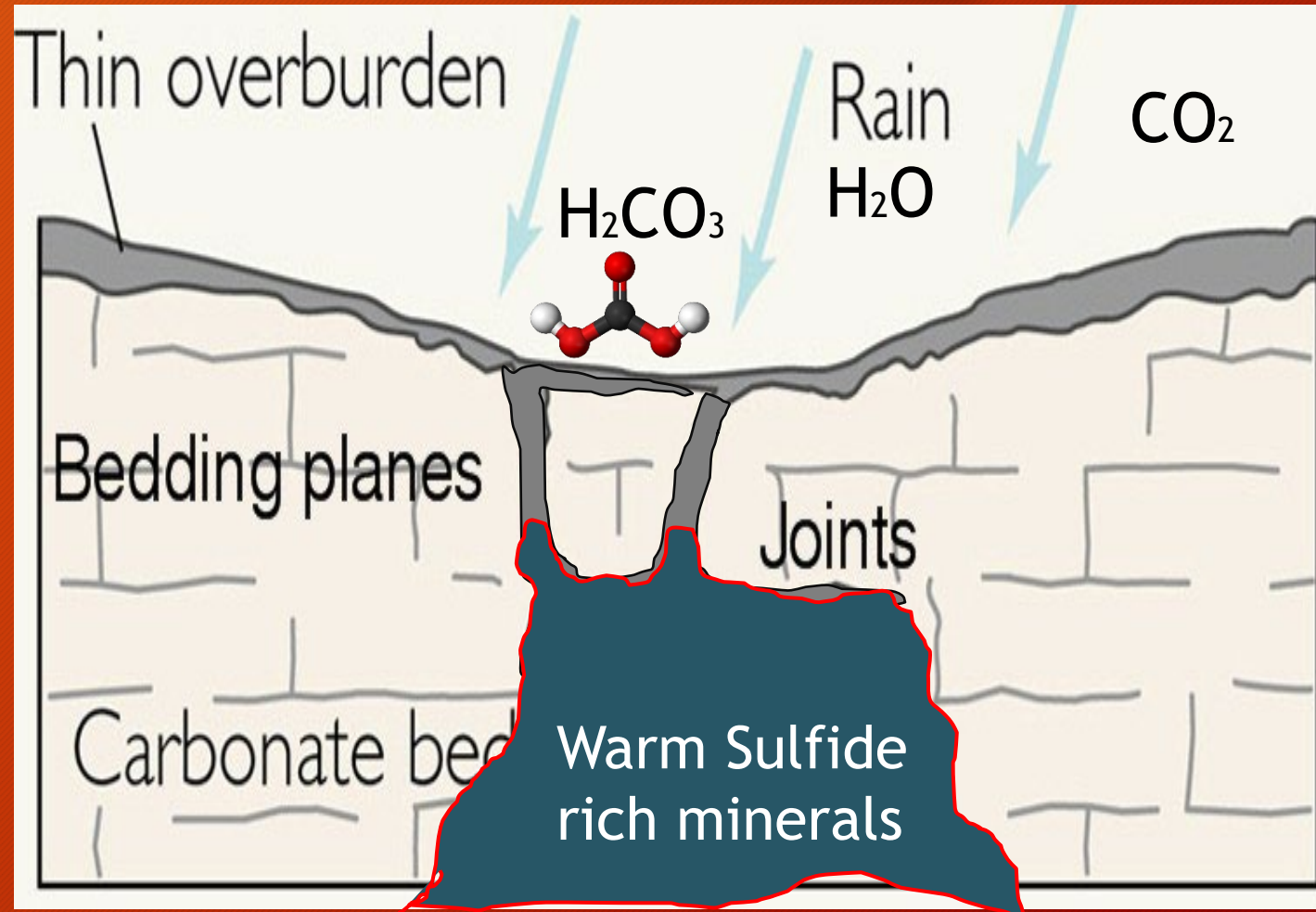


Upper Mississippi Valley Zinc and Lead District



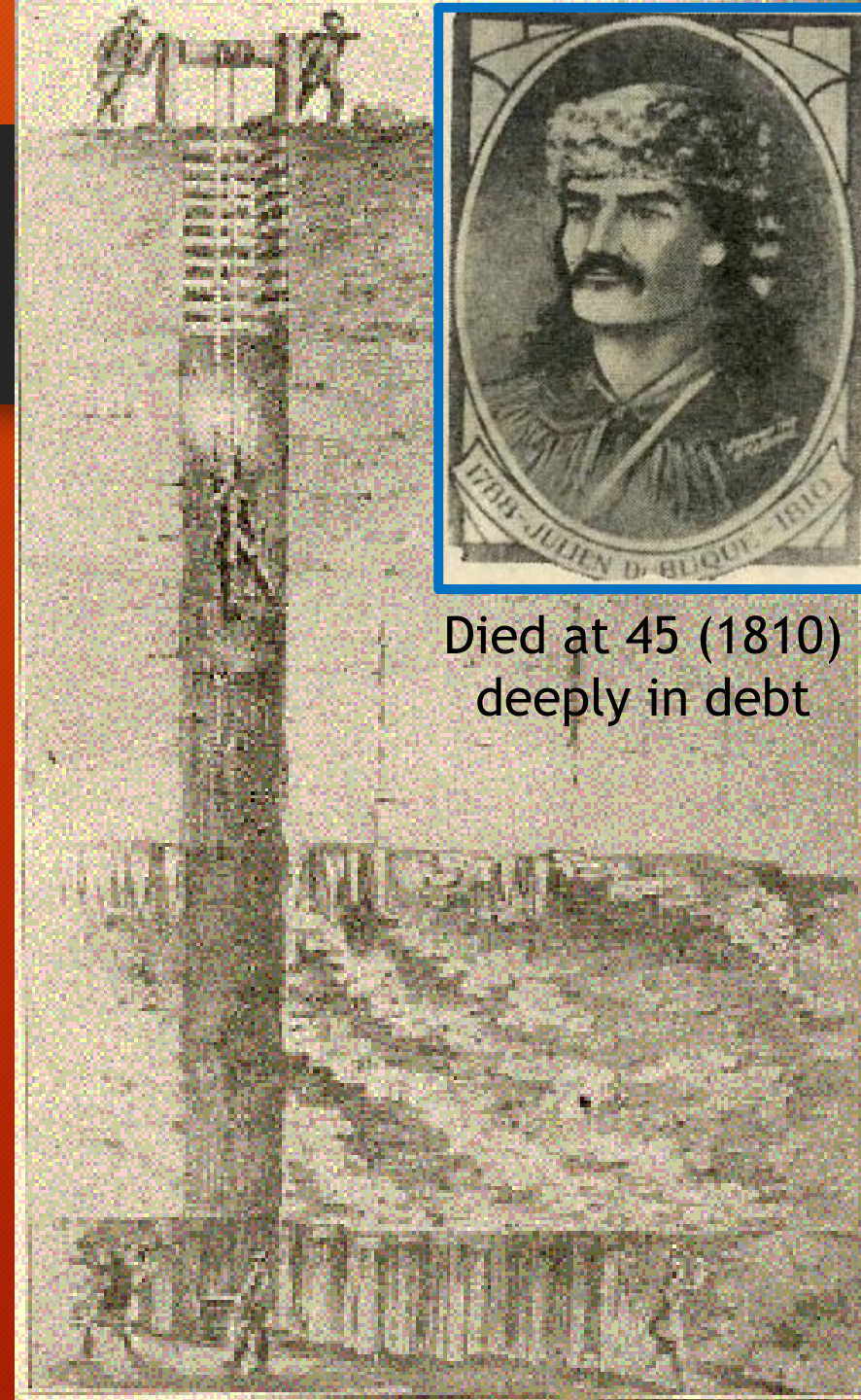
How does Galena & Zinc form in Limestone?

- Space is created, through karst processes
- Warm sulfide-rich solutions migrate upwards and infiltrate the new space
- Sulfide minerals precipitate out of solution and along the edges of these new spaces
- The Mississippi cuts its channel into the landscape and lowers the water table
- Exposing the sulfide minerals, creating Iron sulfide, Lead sulfide, and Zinc sulfides



Lead and Zinc Mining 1788-1810

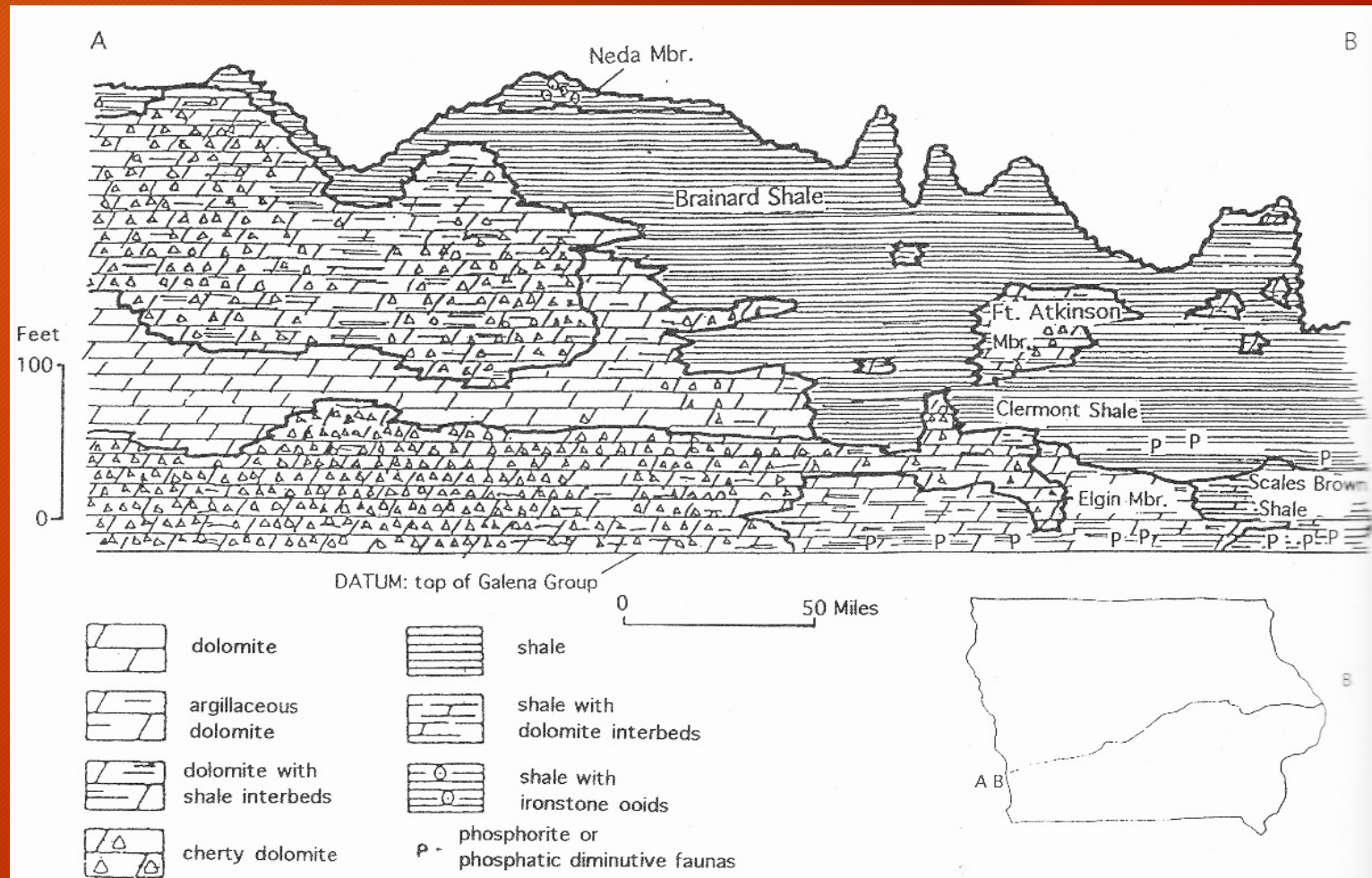
- Spain ruled Iowa via the Treaty of Paris (1763) as a product of the French and Indian War (1756-1763)
- Julien Dubuque became friends with the local Meskwaki, eventually marrying Potosa and entering their culture as *Little Night*.
- Julien, identified the mineral resources and with the Meskwaki's permission began mining
- Julien, requested ownership/confirmation of his land from the Spain, and it was granted in 1796. 'The Mines of Spain'



Died at 45 (1810)
deeply in debt

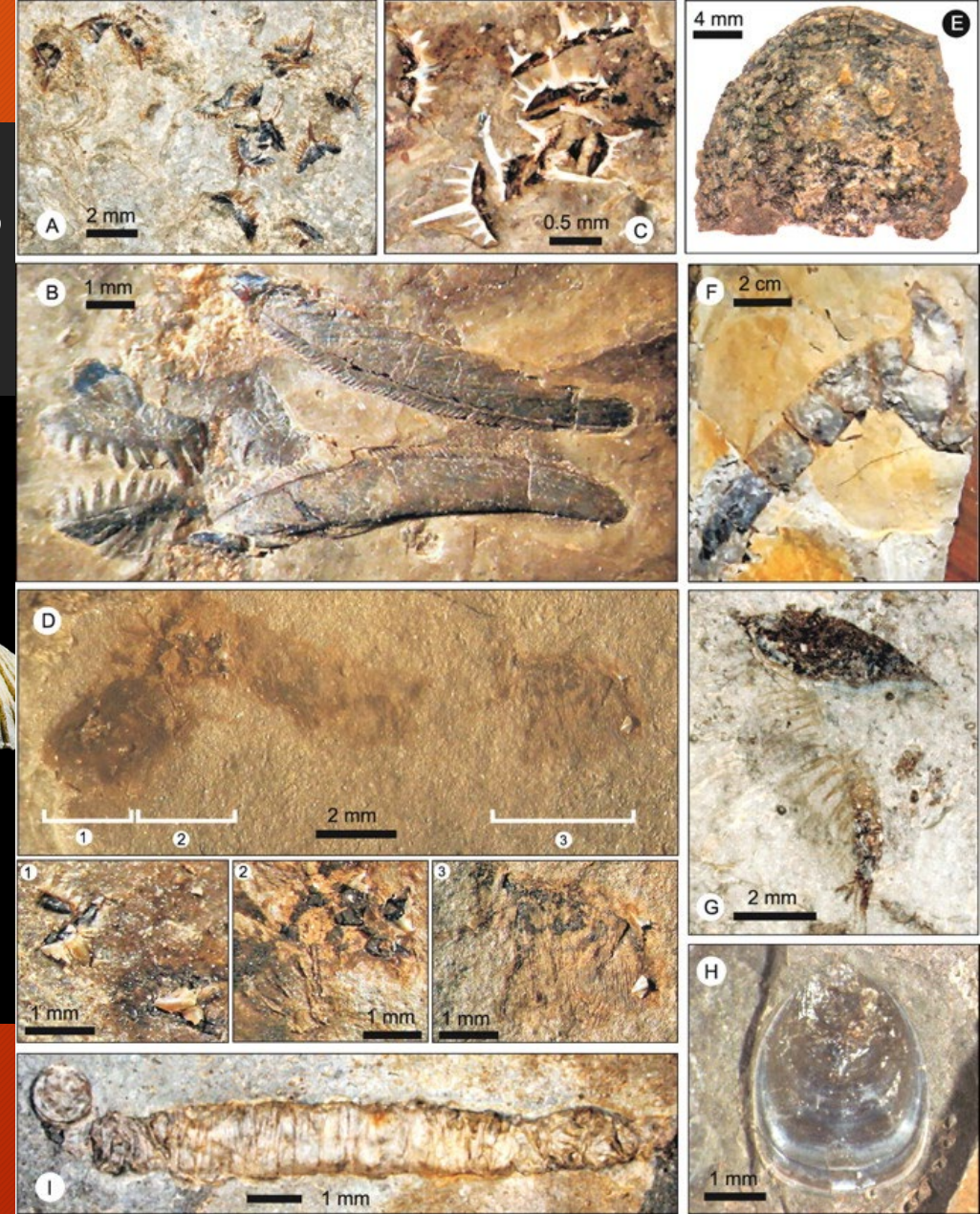
Maquoketa Formation

- Thick impermeable shale
- Large caverns were excavated under Johnson and Polk counties to seasonally store liquefied petroleum gas
- Enables the pipeline industry to store their product so that they can meet demand during the winter

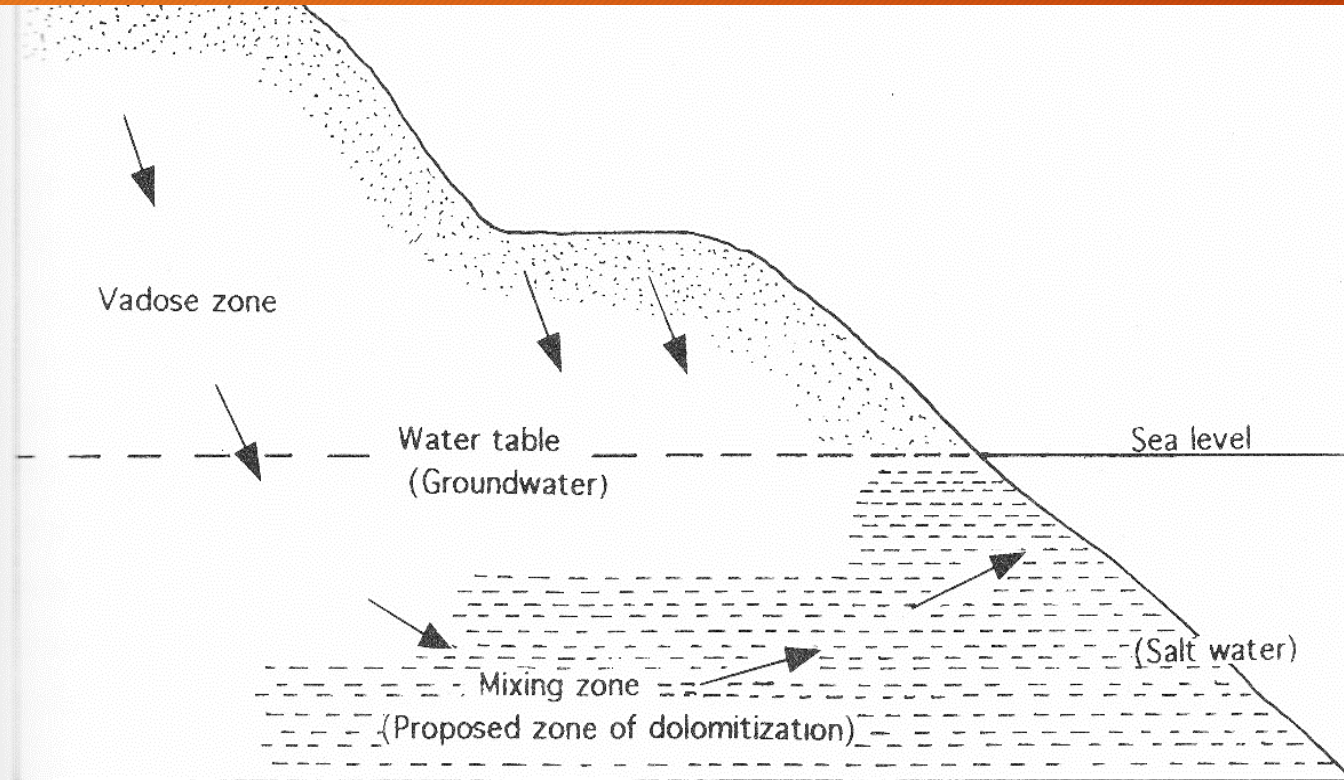


Ordovician Life: Warm shallow seas = ☺ Life

- Brachiopods
- Bryozoans
- Corals
- Receptaculitides
- Mollusks
- Worms
- Arthropods
- Echinoderms
- Graptolites
- Conodonts



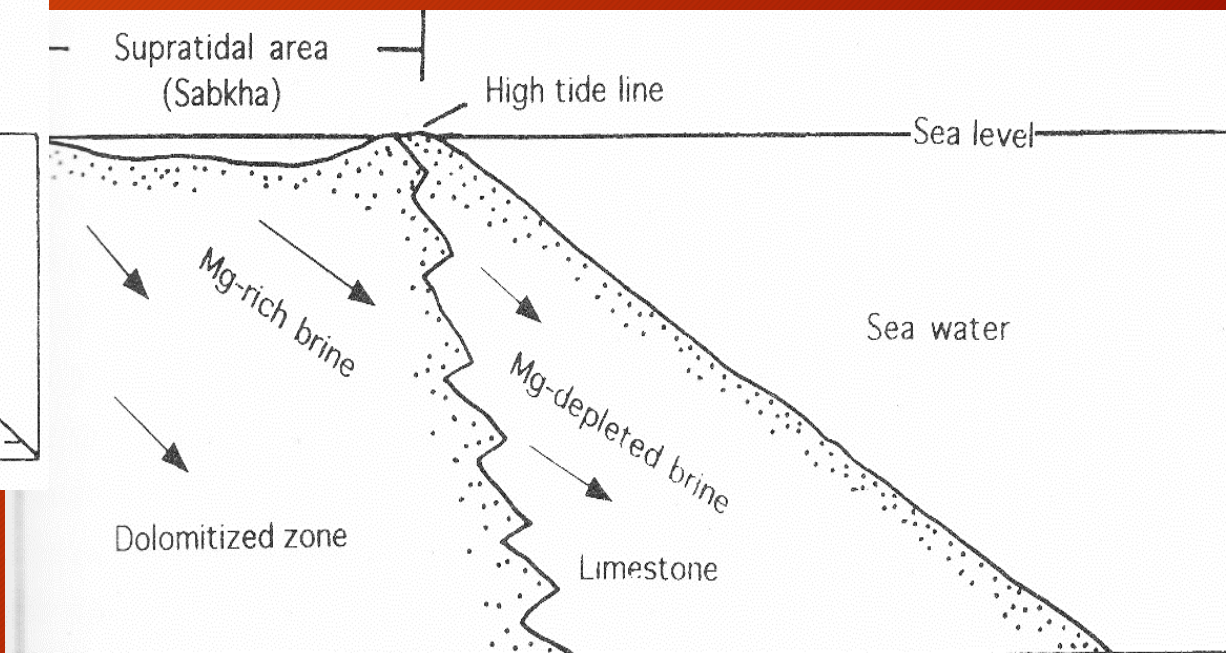
Process of Dolomitization

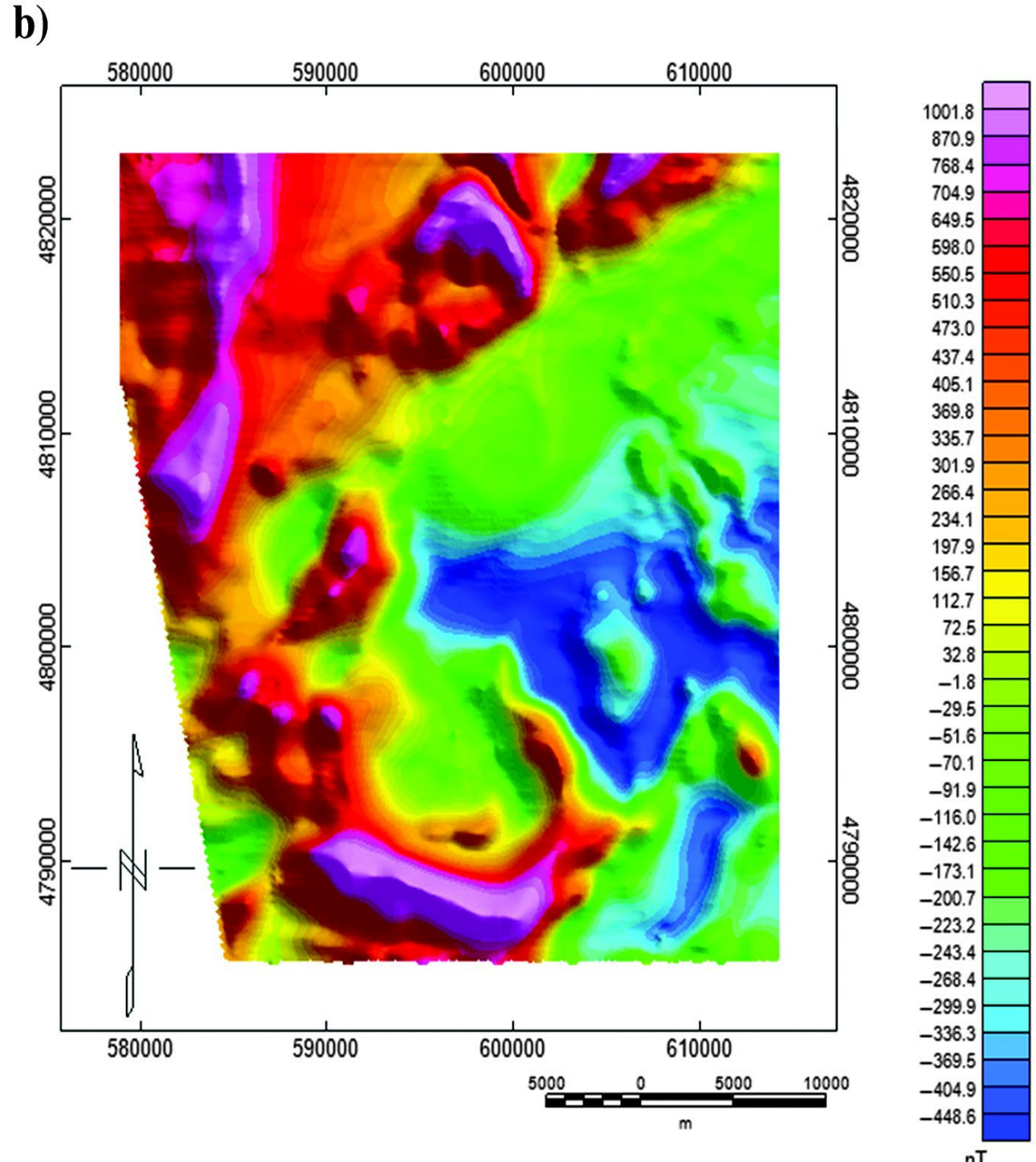
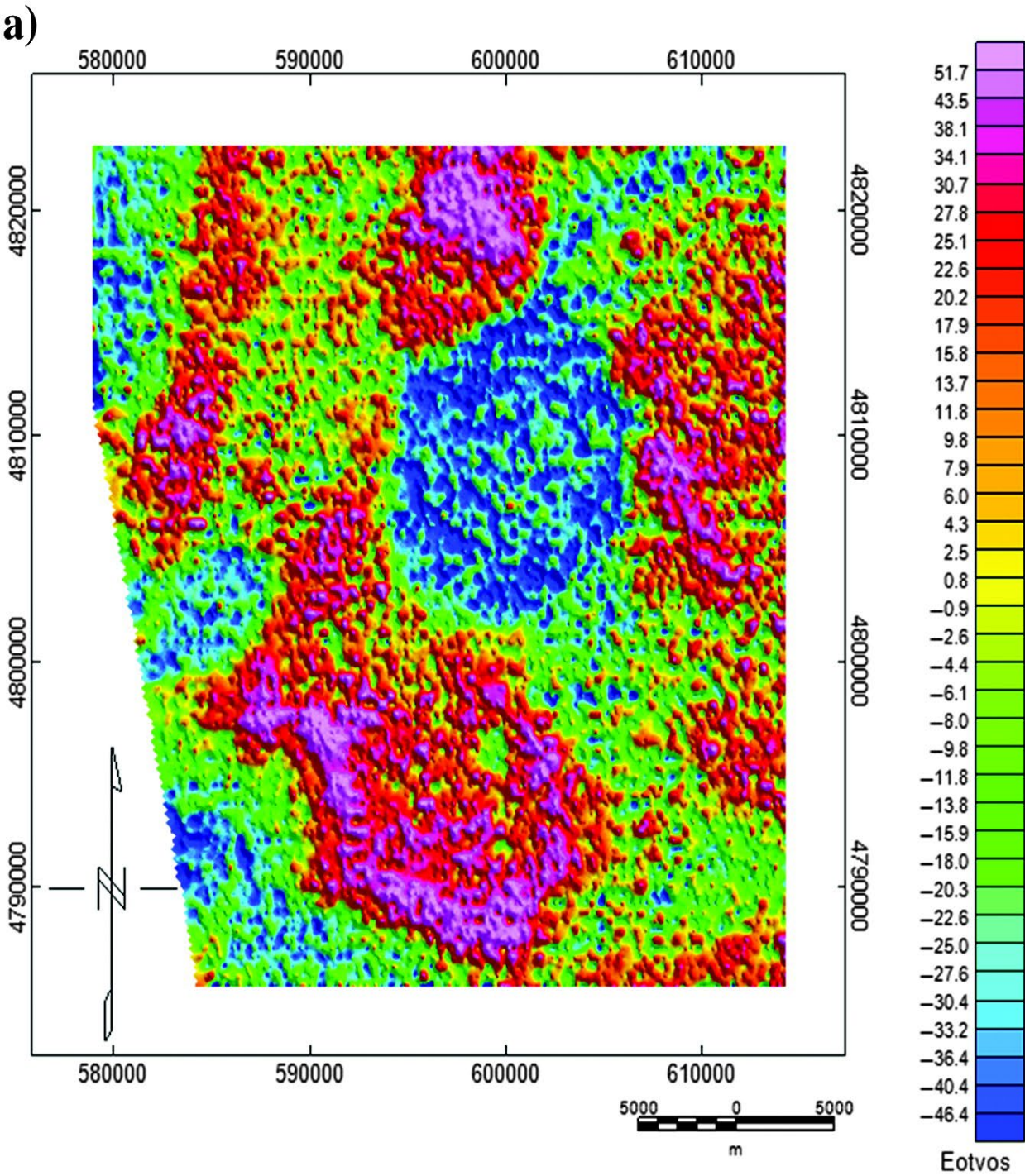


CaCO_3

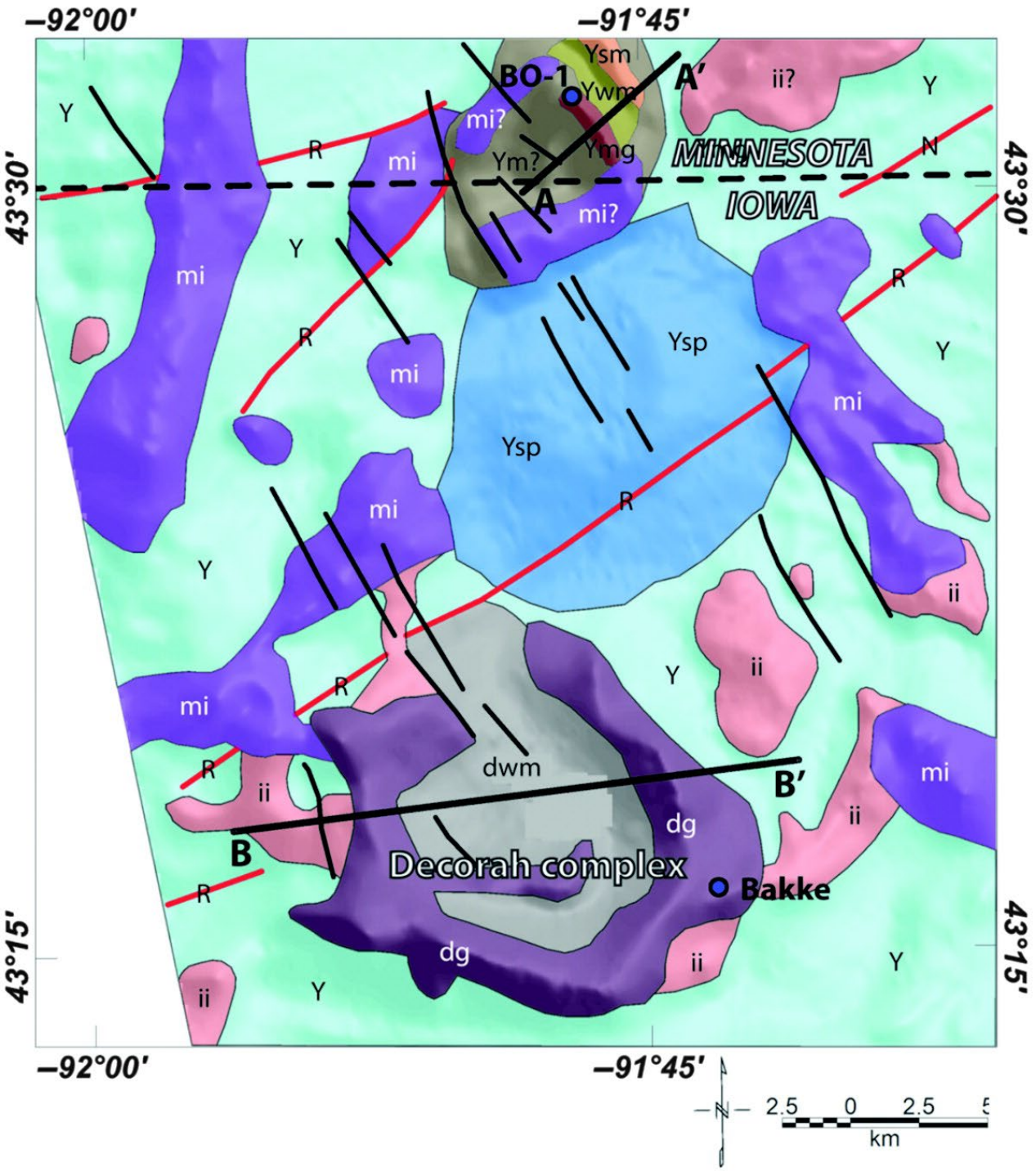
Mg replaces some Ca

$\text{CaMg}(\text{CO}_3)_2$









Possible Keweenawan (~1.1 Ga) rocks, largely undeformed

- ii intermediate or silicic intrusive rocks (strongly magnetized but not dense)
- mi mafic intrusive rocks (strongly magnetized and dense)
- N-polarized diabase dike
- R-polarized diabase dike
- dwm weakly magnetized rocks of Decorah complex (possibly 1500-1430 Ma)
- dg gabbro of Decorah complex (possibly Mesoproterozoic)

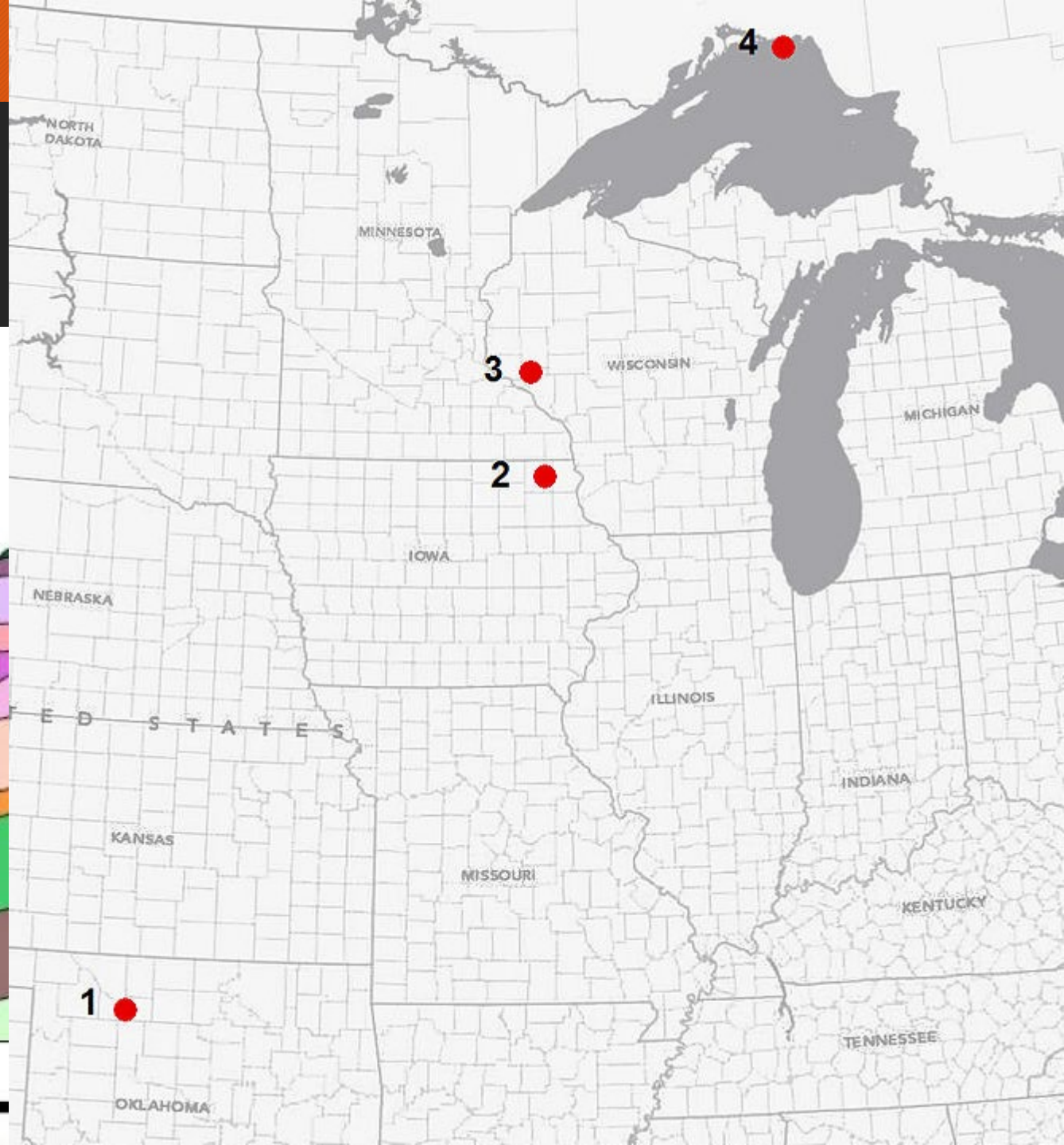
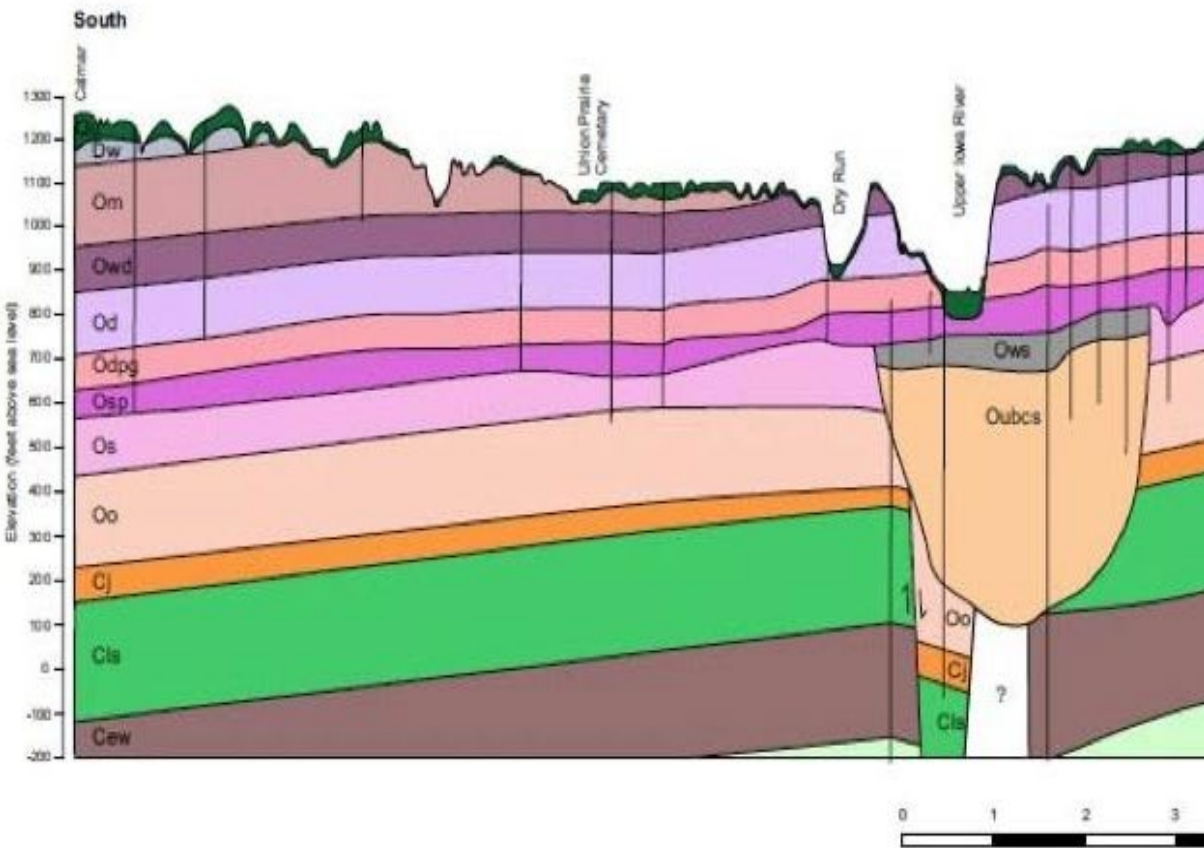
Yavapai province (1.8-1.72 Ga) rocks, some presumed

- Ysm strongly magnetized part of subvertically dipping layered intrusion
- Ywm weakly magnetized part of subvertically dipping layered intrusion
- Ymg 1760 Ma metagabbro; part of subvertically dipping layered intrusion
- Ym? undifferentiated mafic rocks, spatially related to layered intrusion
- Ysp silicic pluton: S-type granite?
- Y undifferentiated Yavapai province rocks: metavolcanics, plutons, & metasediments

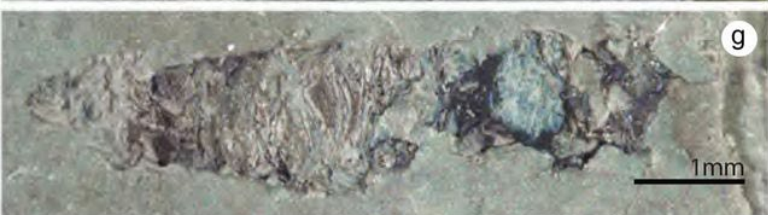
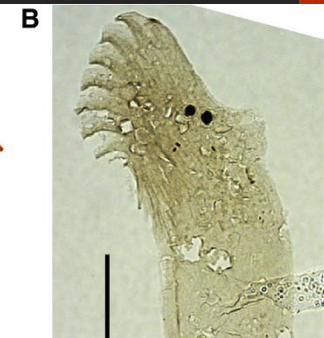
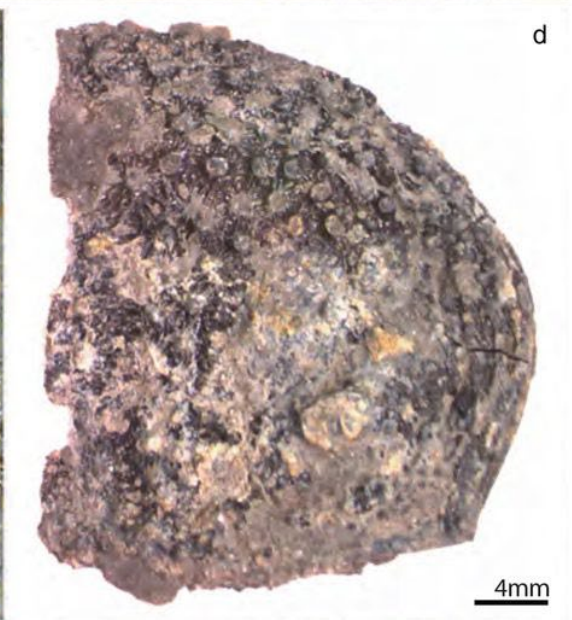
A — A' line of cross section model

- borehole penetrating Proterozoic rocks
- possible fault

Decorah Impact Structure



Decorah Lagerstätten



Eurypterids - Sea Scorpions

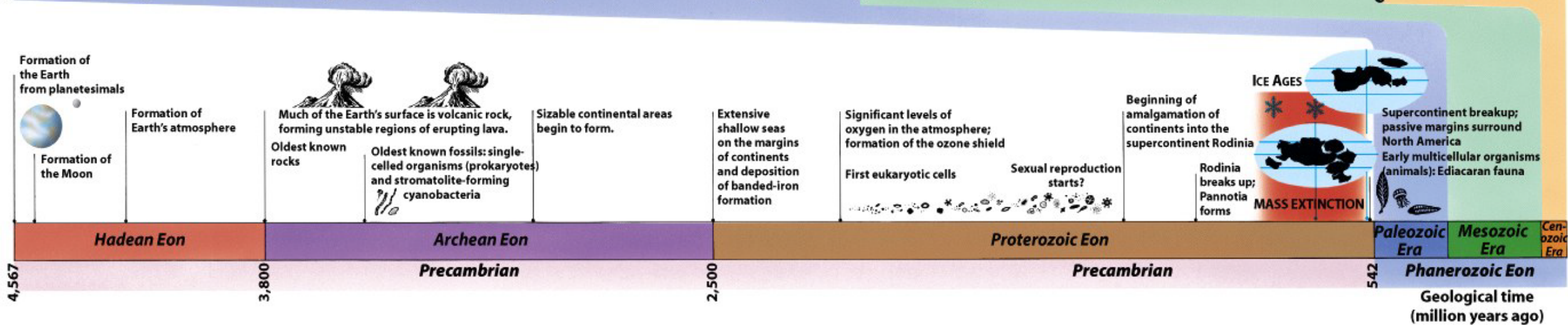
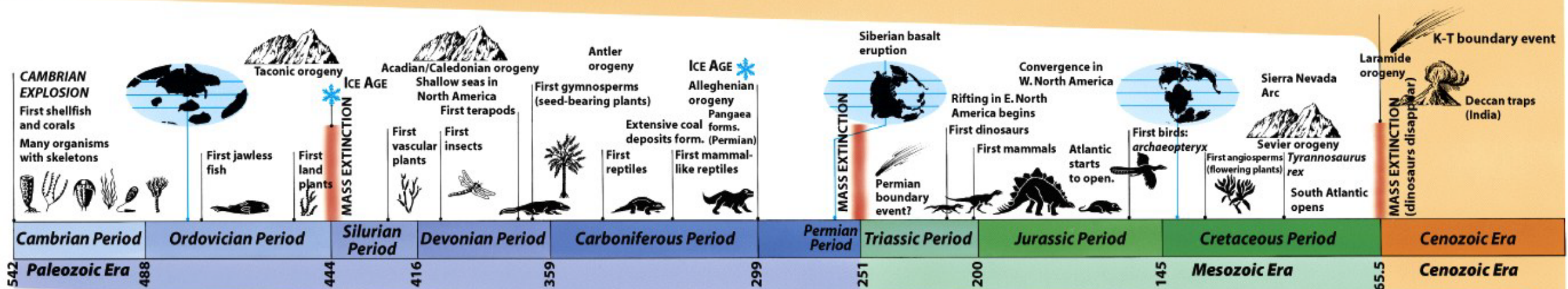
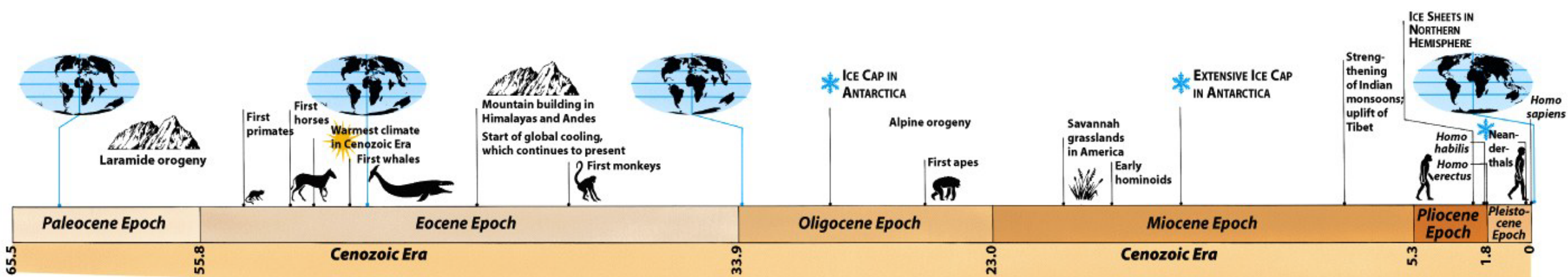
Extinct arthropods



Silurian - Dolomite and Carbonate Mounds

419 Ma
To
443 Ma

- Six Dolomite and two limestone formations, that provide the foundation for many of Eastern Iowa's State parks.
- There are five marine Transgression to Regression phases recorded in Iowa's Silurian Formations.
- These Silurian rocks have great economic value (agricultural lime, road aggregate, aggregate for concrete, building stone and as bedrock aquifers).
- Towards the end of the Silurian there was another period of weathering and erosion that created an unconformity between the Silurian and Devonian.

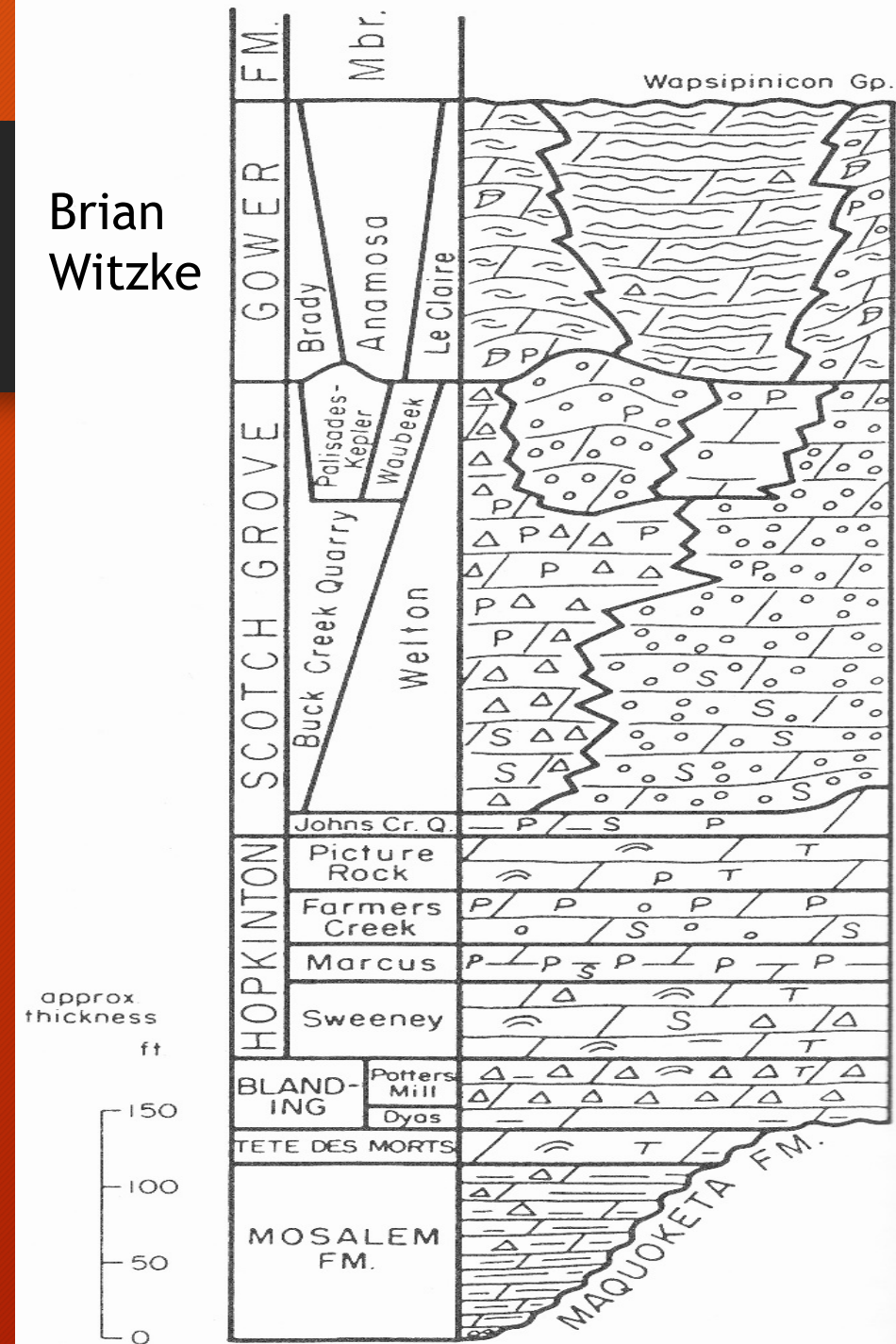


Geological time (million years ago)

Silurian stratigraphy

- Dolostone formations
 - Mosalem
 - Tete des Morts
 - Blanding
 - Hopkinton
 - Scotch Grove
 - Gower
- Limestone formations
 - Waucoma
 - Le Porte City

Brian
Witzke



Hopkinton Formation

- Common in eastern Iowa
- Very-fine to coarsely crystalline dolostones with areas of nodular chert
- Contains four members
 - Sweeney
 - Marcus
 - Farmers Creek
 - Picture Rock



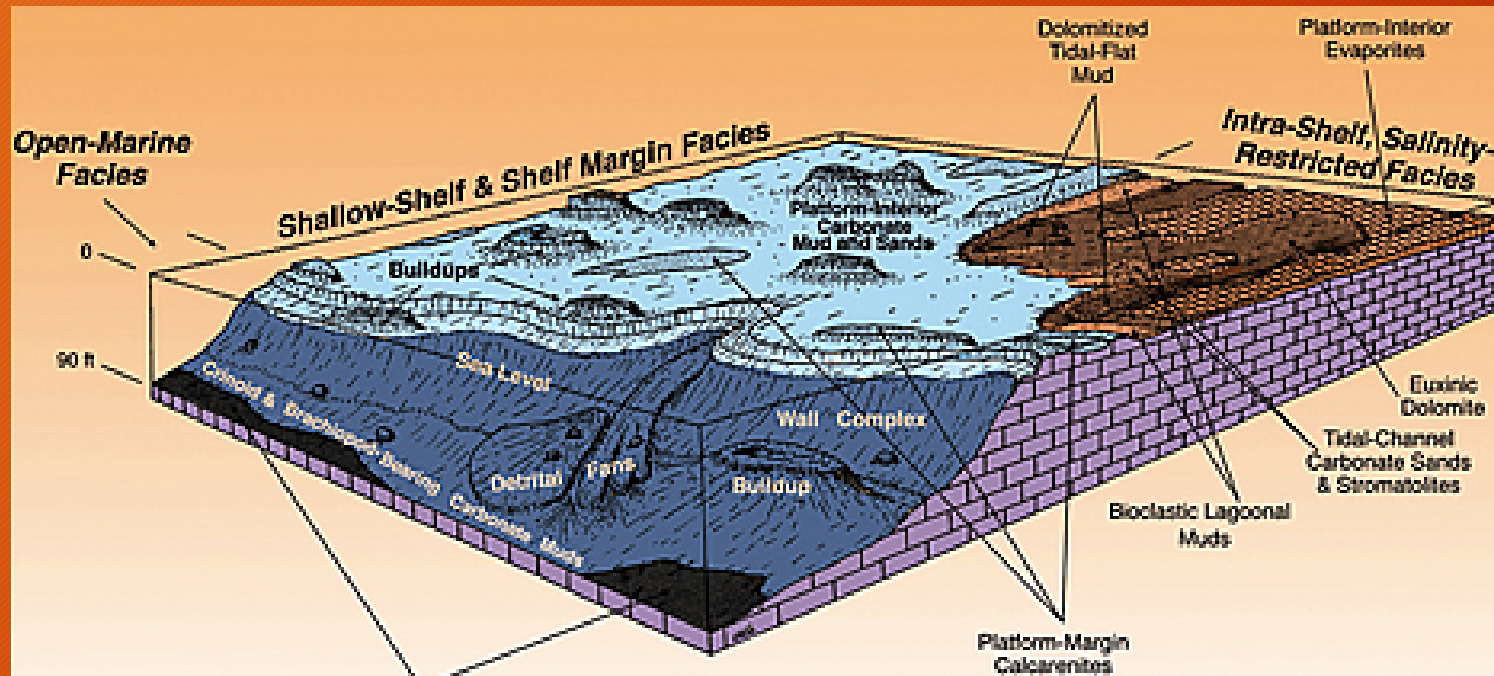
State Parks

- Maquoketa Caves State Park
- Backbone State Park
- Mississippi Palisades State Park
- Picture Rock County Park (Jones Co.)



Scotch Grove Formation

- Overlies the Hopkinton Fm. as dolostone with cherty intervals
- Represented by the natural bridge feature at Maq. Caves State Park



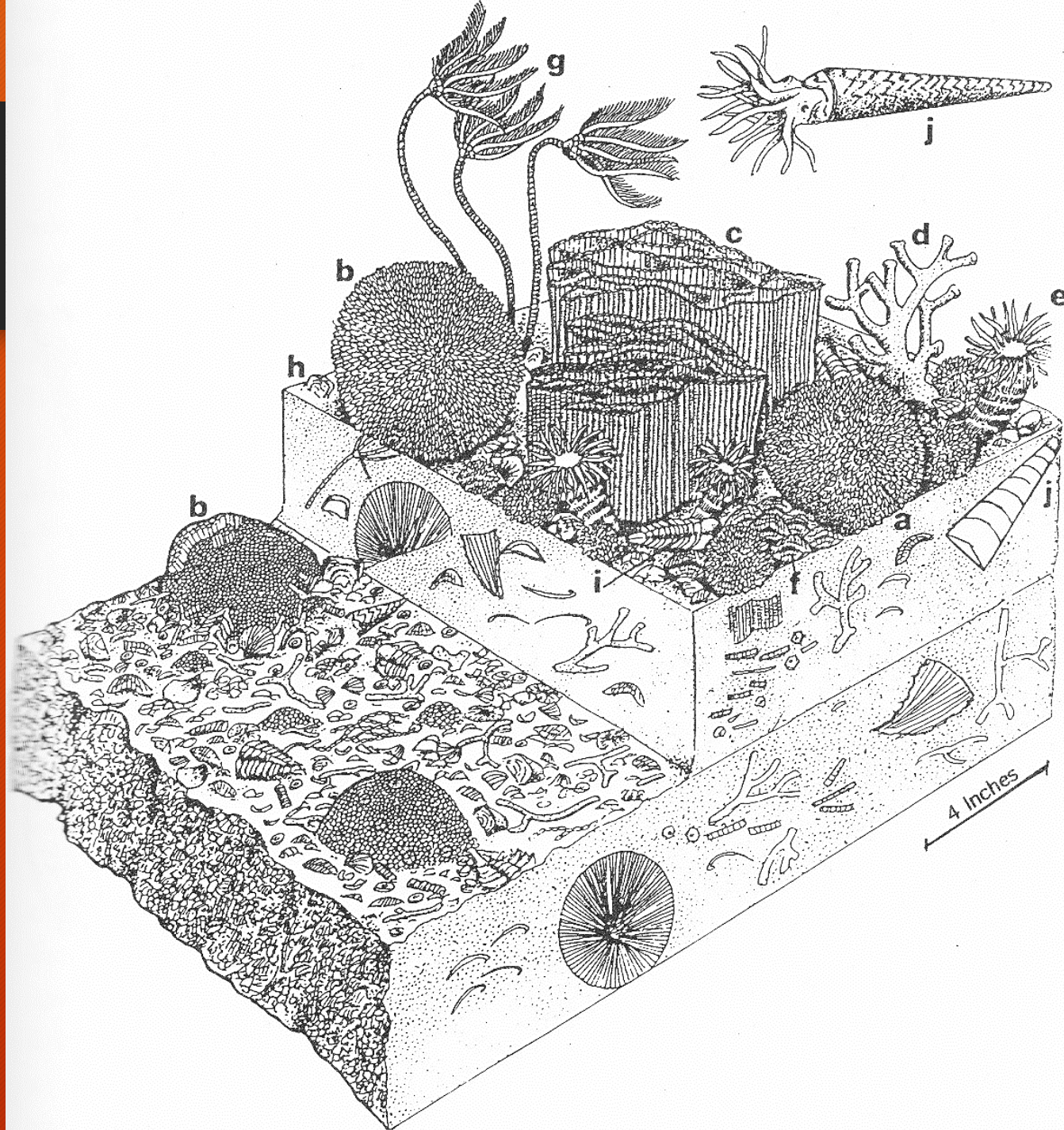
Anamosa Facies - Ideal building stone

- Uniform bedding
- Fine consistent texture
- Used for many of Iowa's early buildings
 - Rock Island Arsenal (IL)
 - Anamosa Prison
 - Stone City, IA
 - Cornell College
 - Herbert Hoover Presidential Lib.
 - Three large buildings in downtown Minneapolis

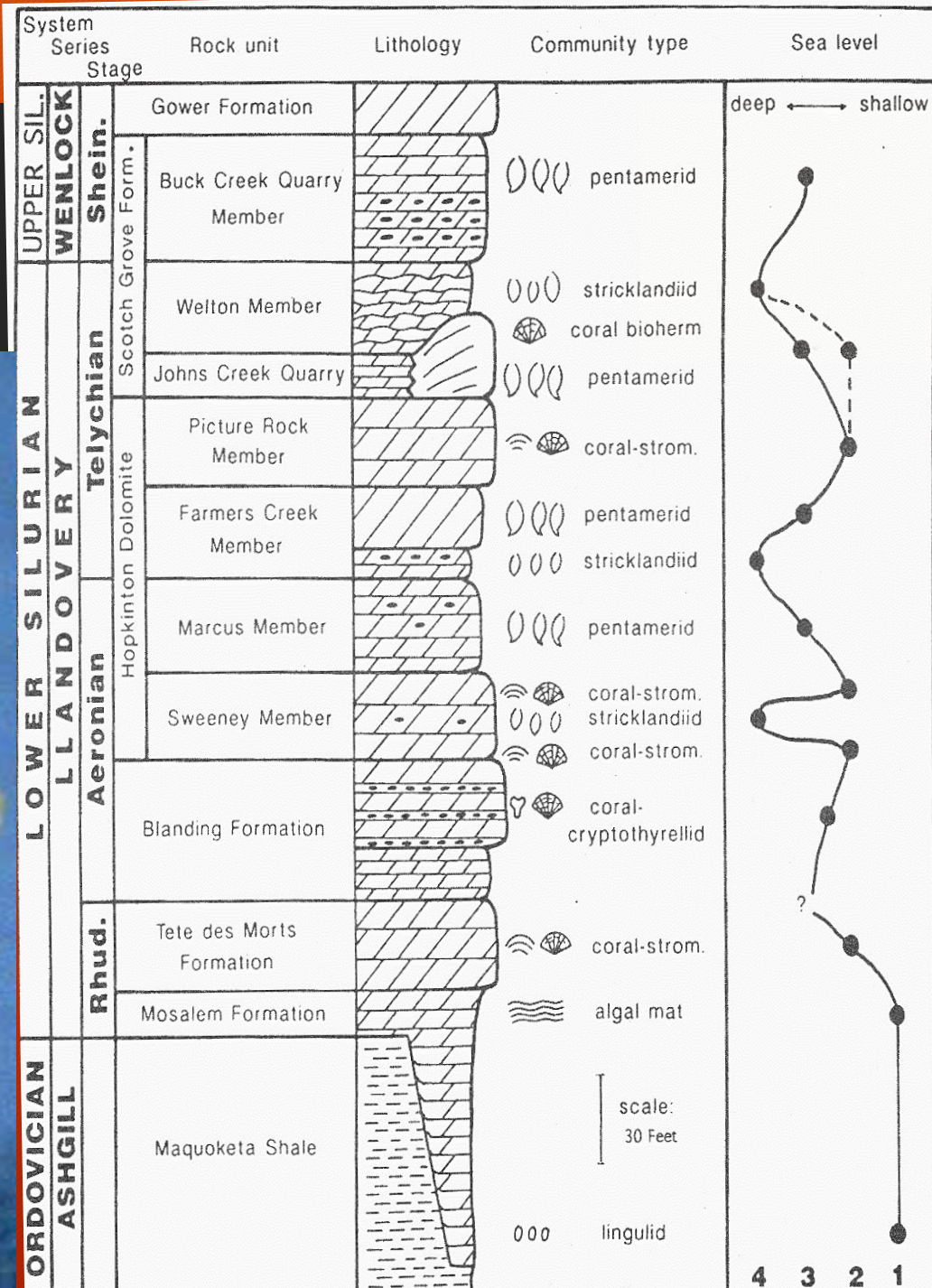


Silurian Life

- Colonial corals
 - Favosites
 - Halysites
- Solitary corals
- Brachiopods
- Algae



Applied paleontology

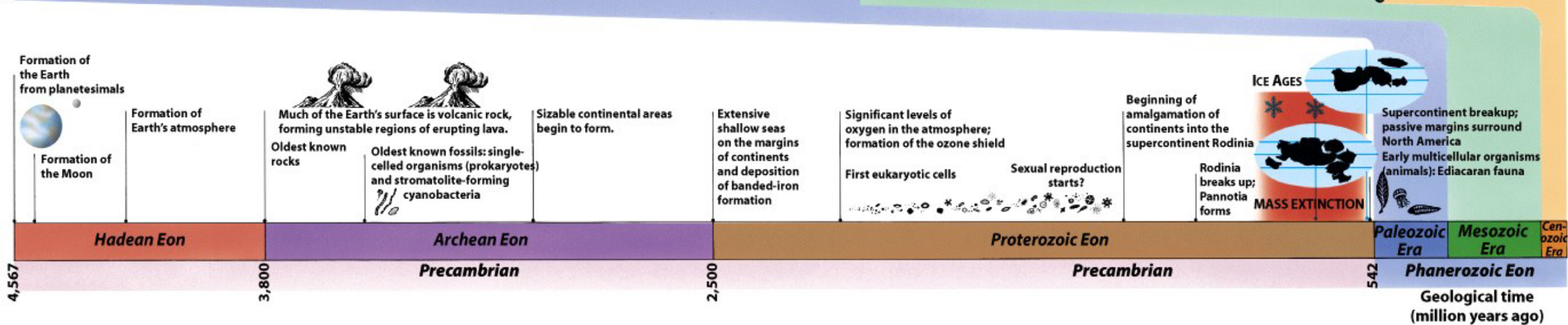
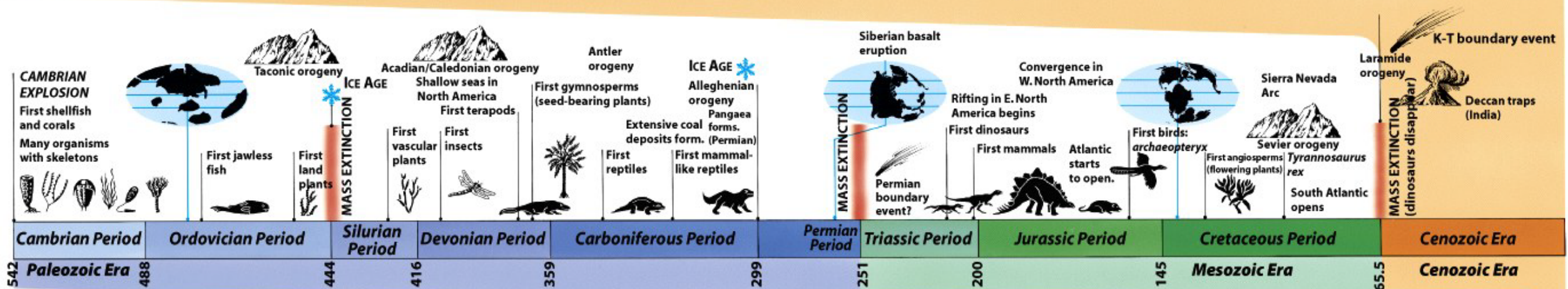
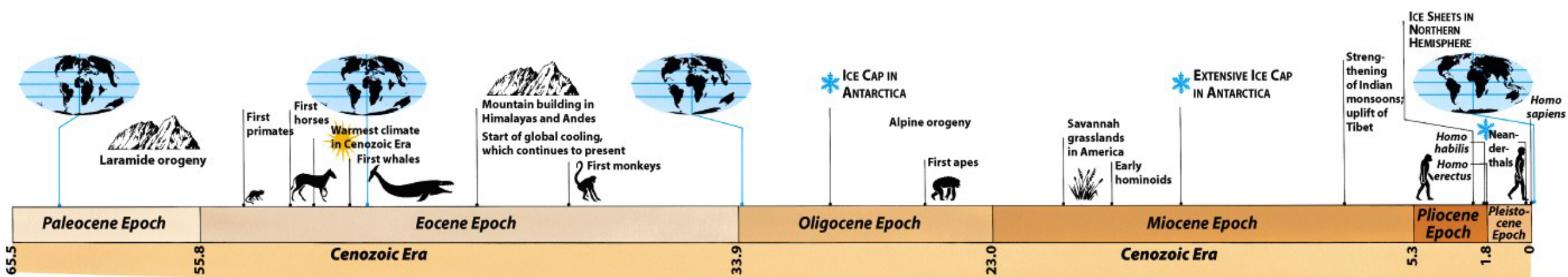


4 3 2 1

Devonian - A Marine Extravaganza 😊

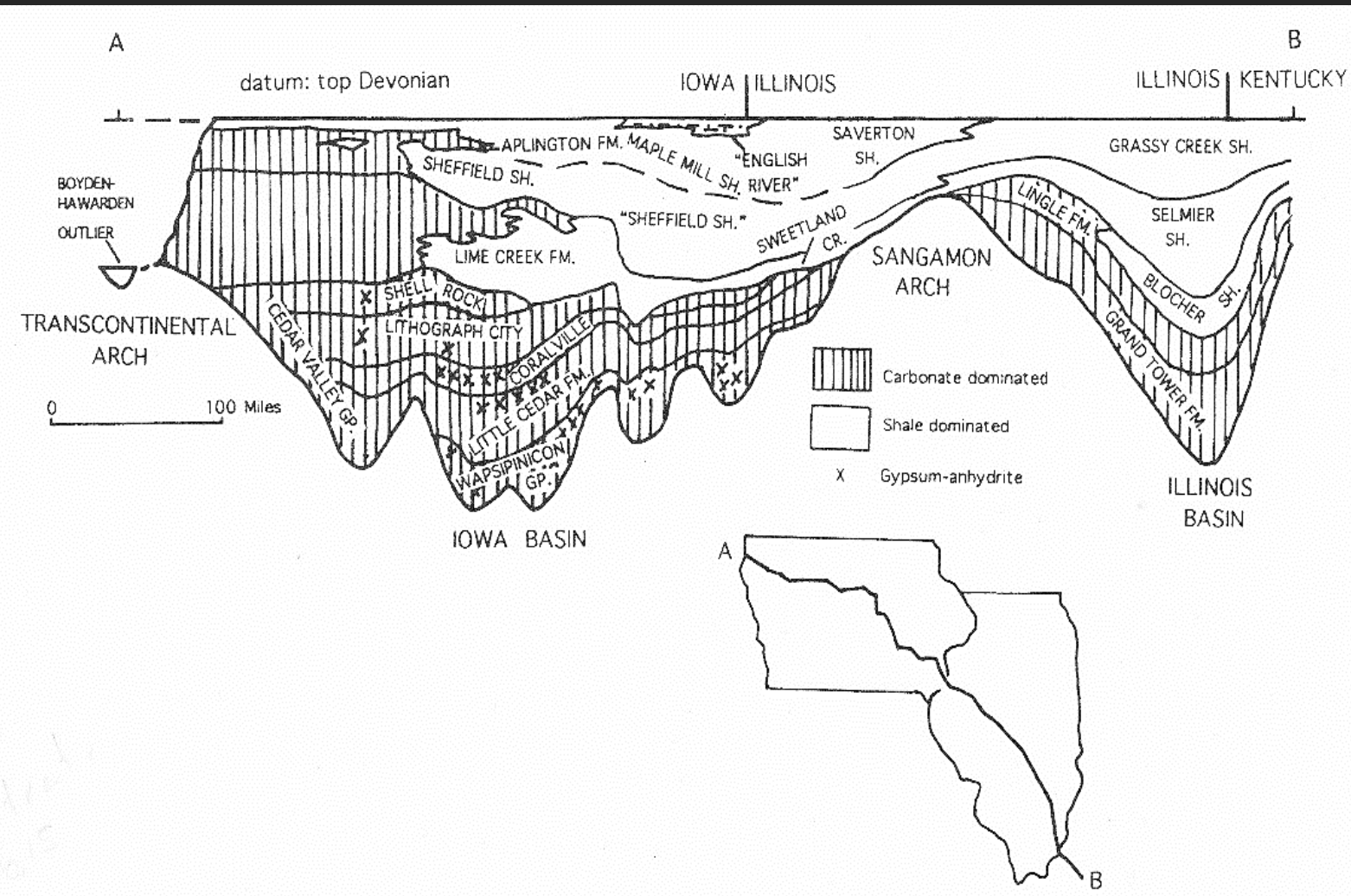
358 Ma
To
419 Ma

- The Devonian System contains 13 formations.
- Economically valuable resource for road and concrete aggregate in eastern Iowa and gypsum is mined southeastern and north-central Iowa for Portland Cement.
- The Devonian System also serves as an important aquifer/water source for eastern and north-central Iowa.
- These formations also contain significant and well preserved fossils



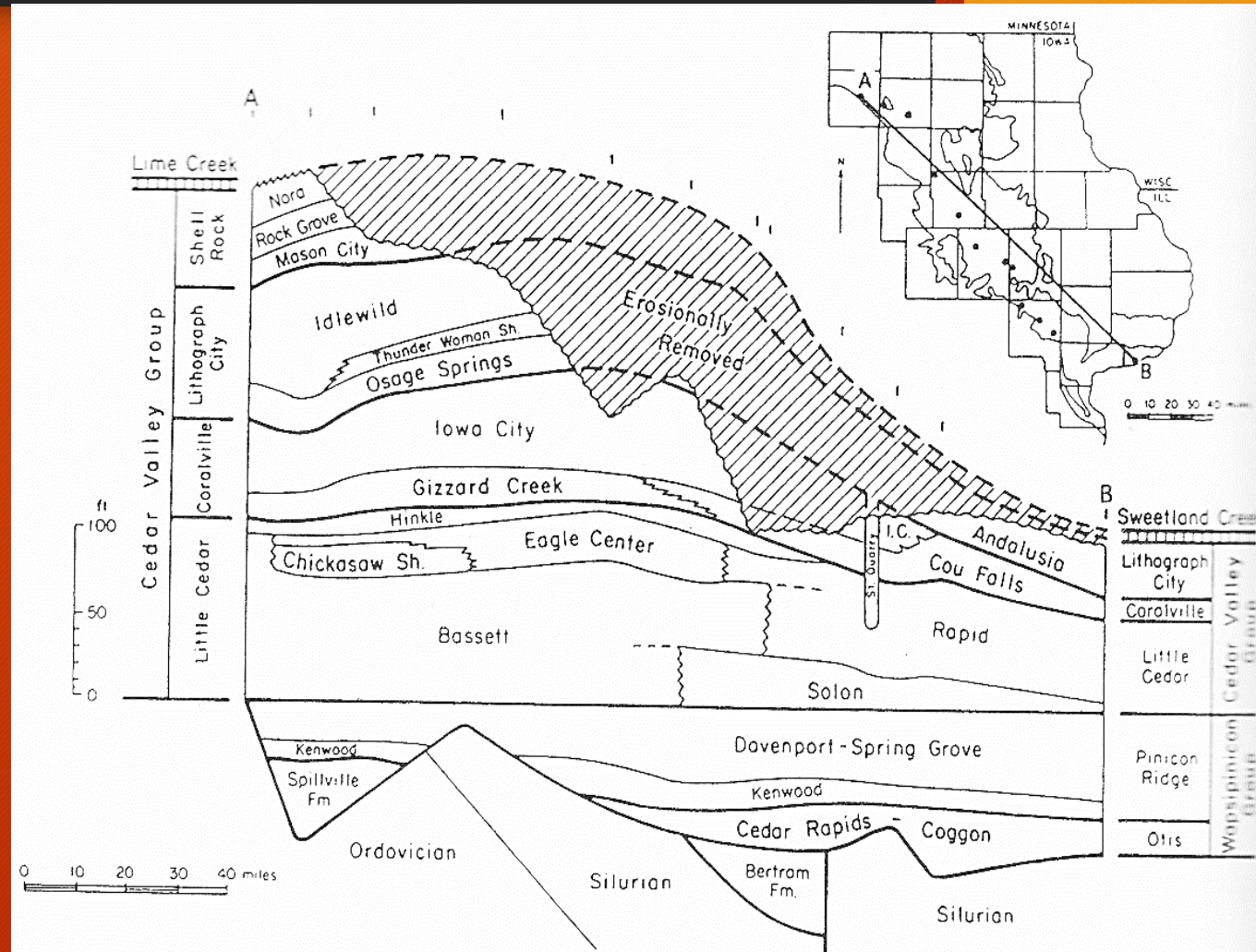
Geological time (million years ago)

Regional stratigraphy



Little Cedar Formation

- Basal Fm. of the Cedar Valley Group
- Solon Member is mostly limestone with abundant fossils
- Rapid Member fine-grained argillaceous limestone that is also fossil rich

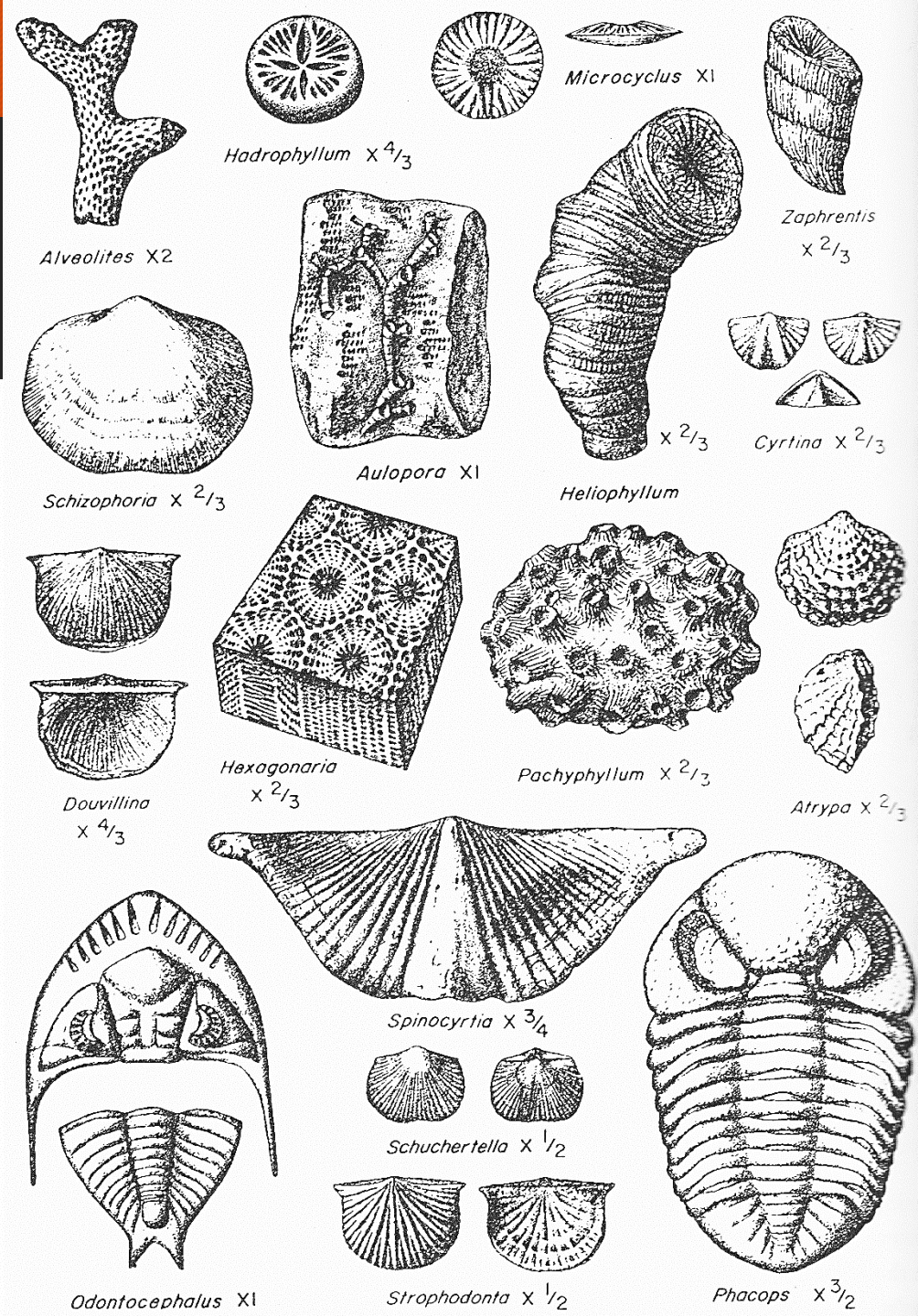
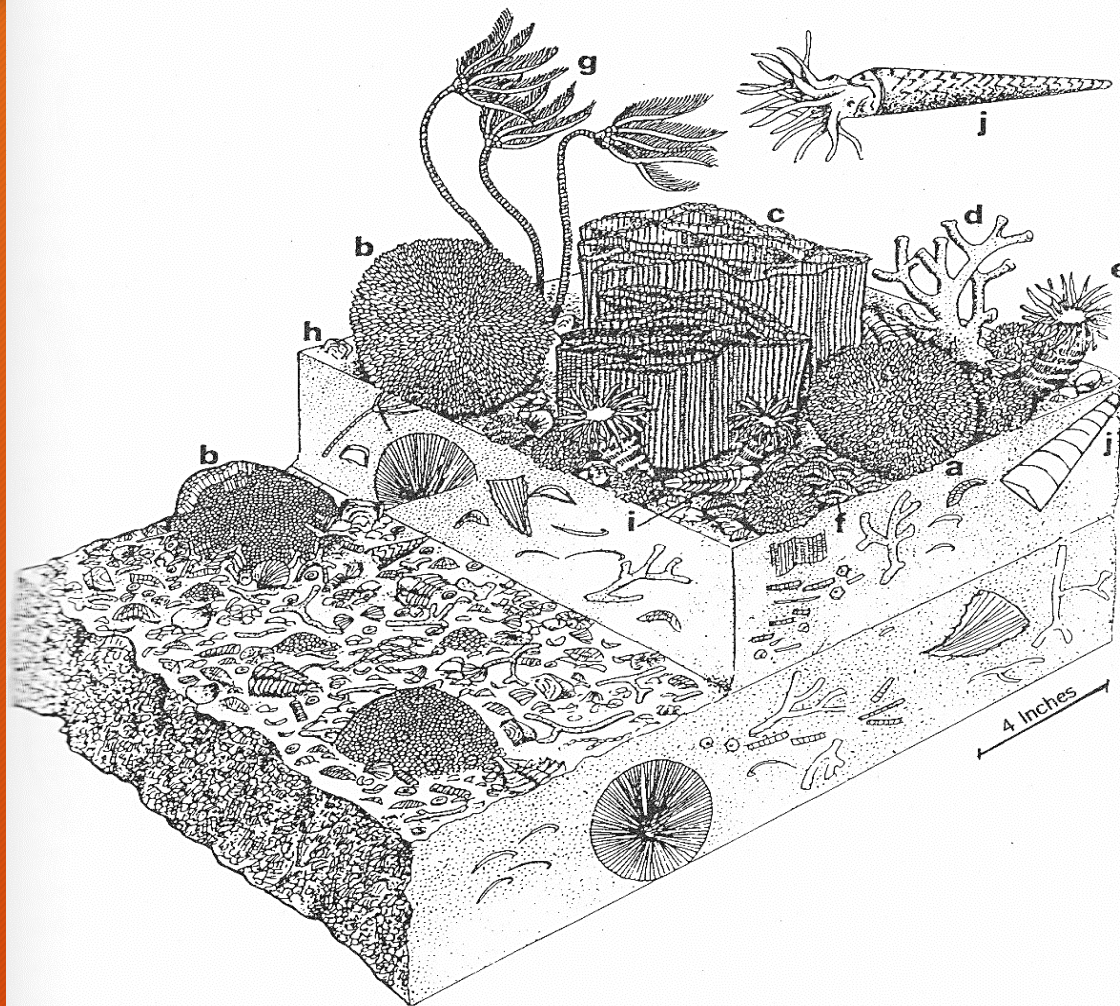


Lithograph City Formation

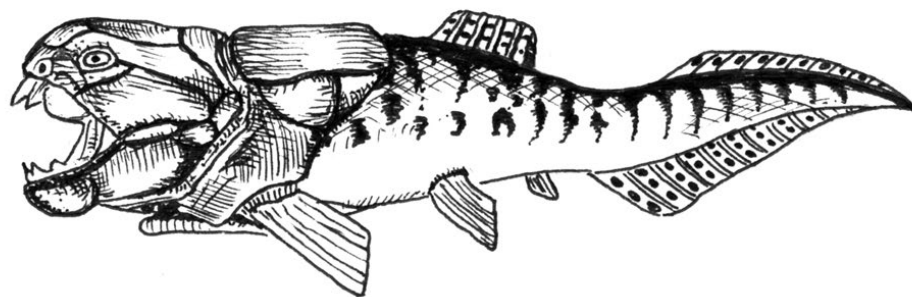
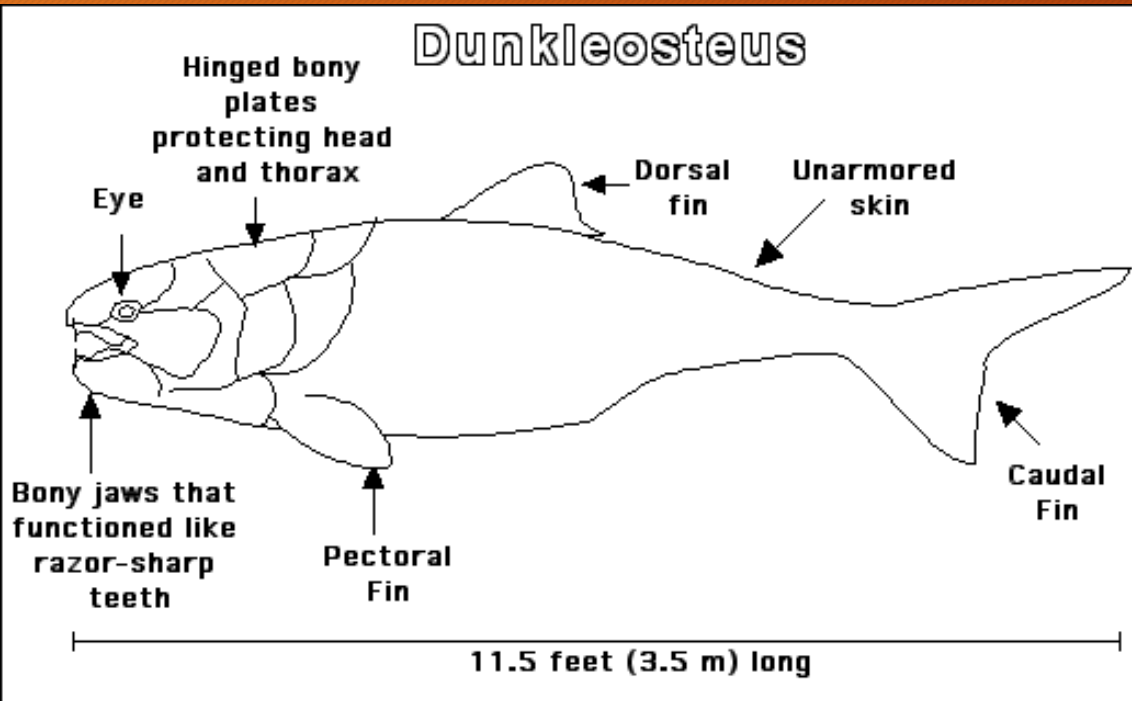
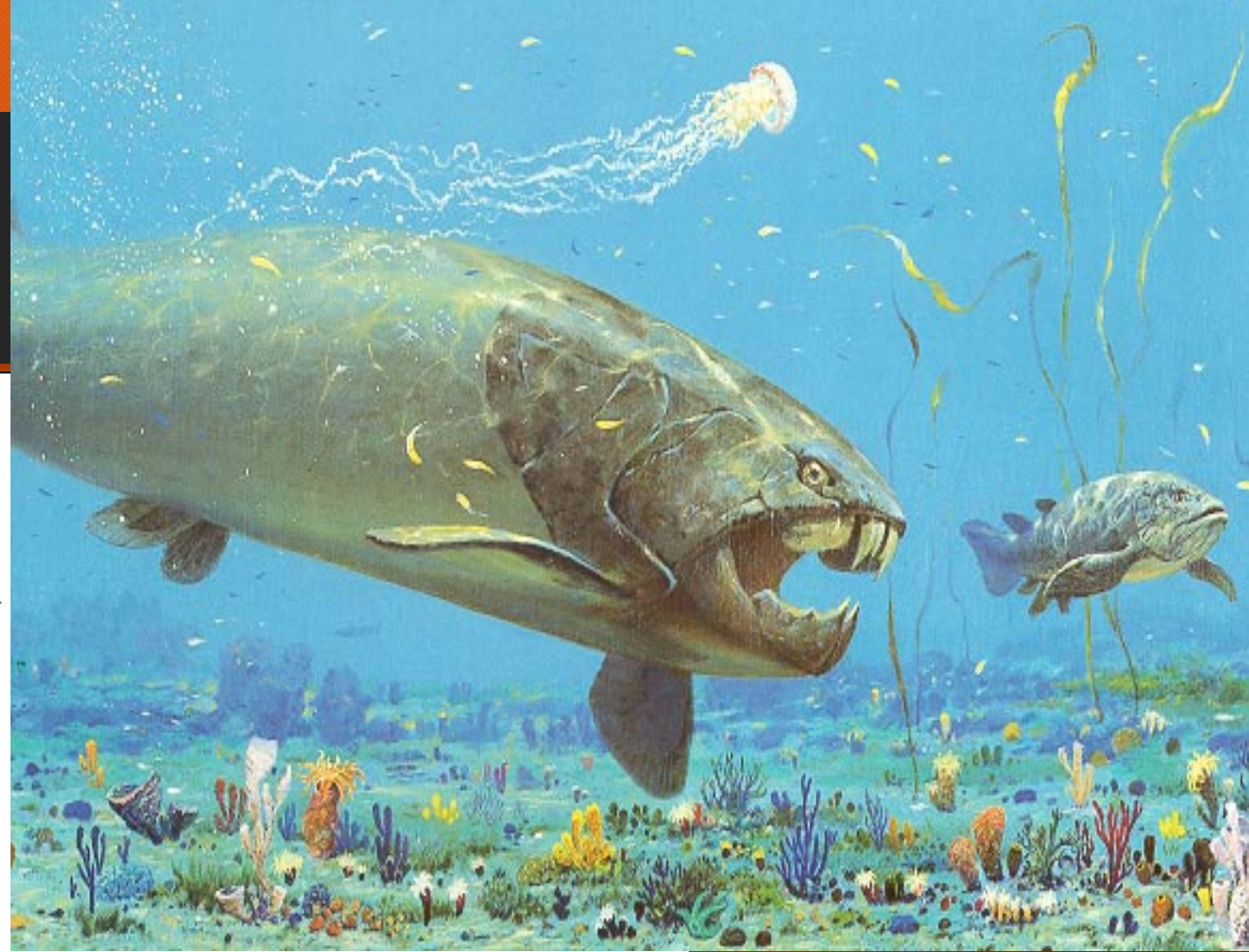
- An extremely fine grained / pure limestone
- Used for Lithography in the early 1900. Lithography City - Floyd-Mitchell county line
- Quarried extensively for road and concrete aggregate as well as Portland Cement



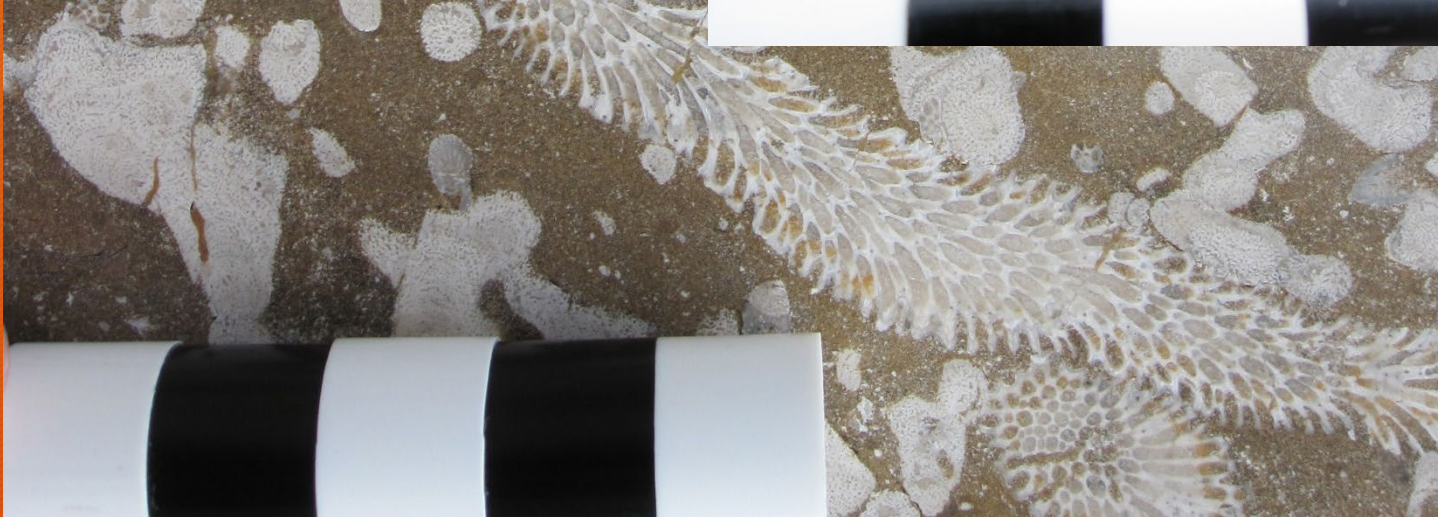
Devonian Life



Devonian Life

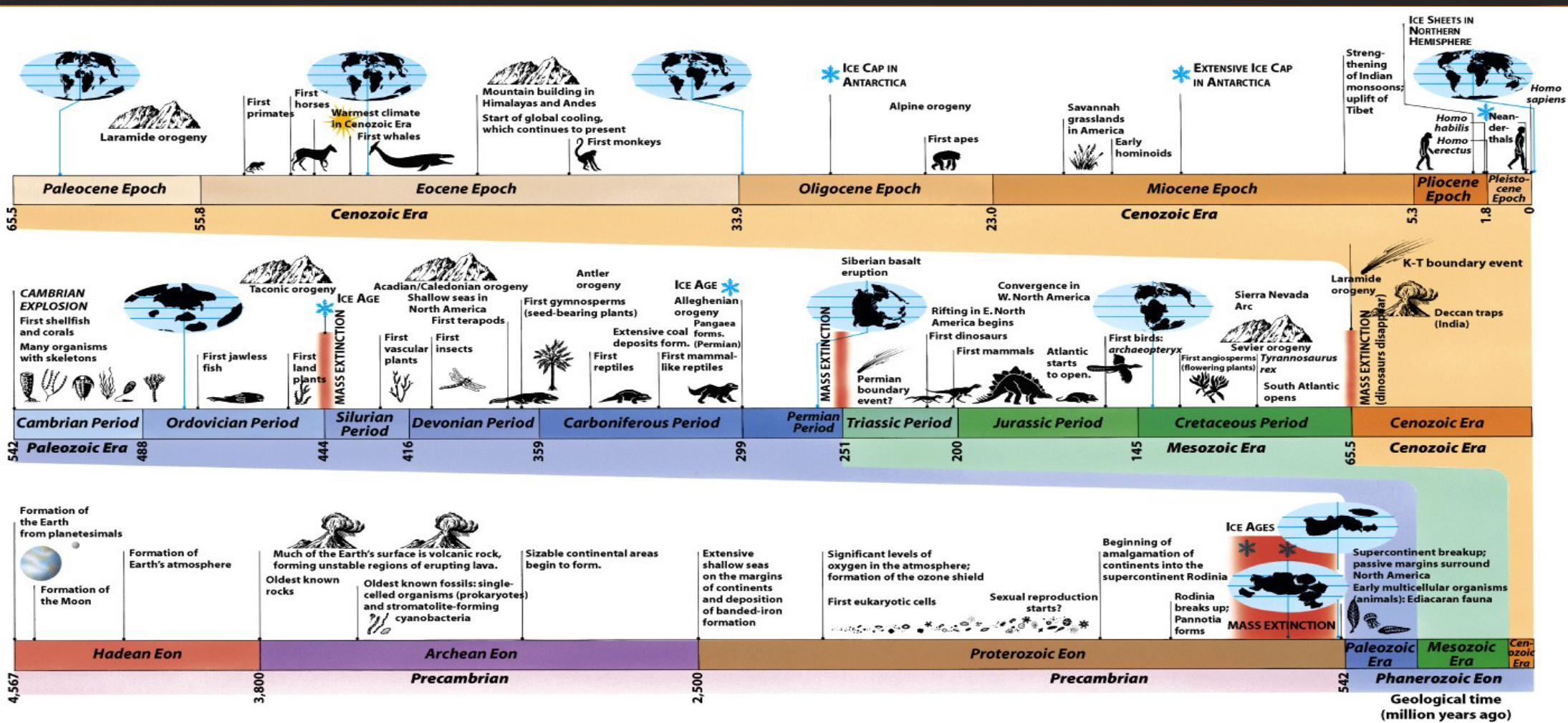


Devonian Life - Via the Devonian Fossil Gorge



Carboniferous - Mississippian - Last major sea

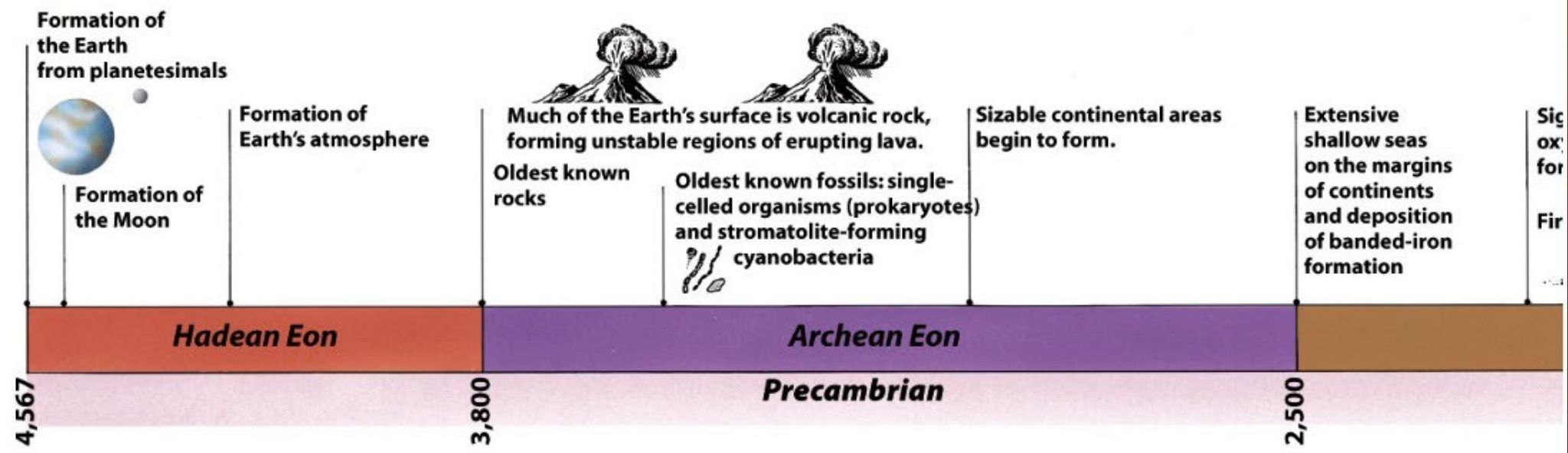
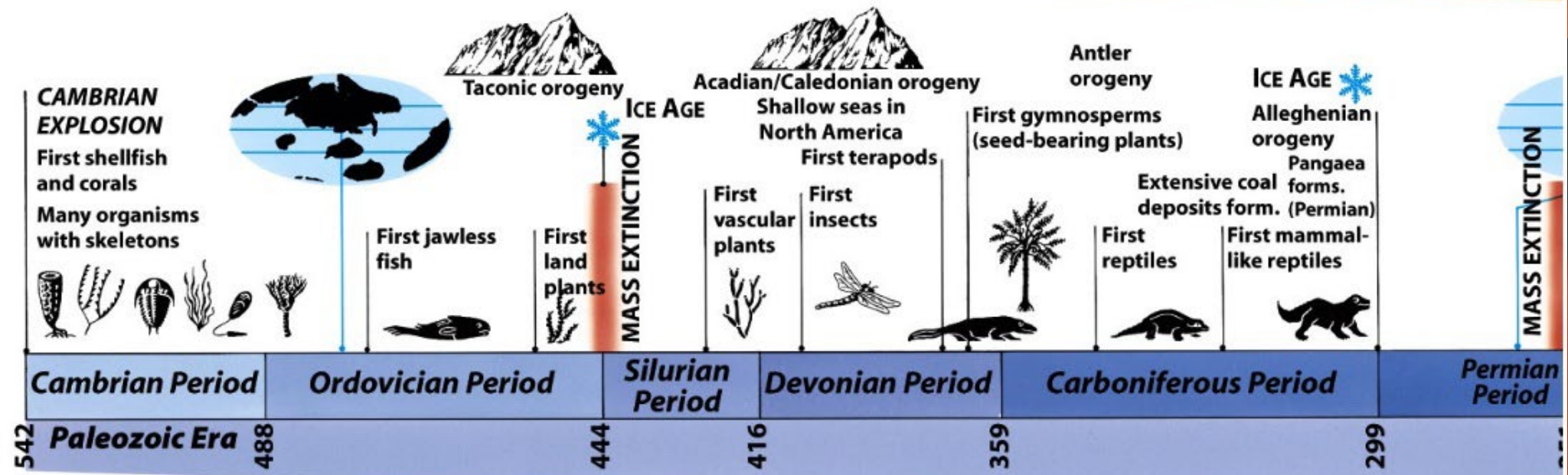
323 Ma
To
358 Ma



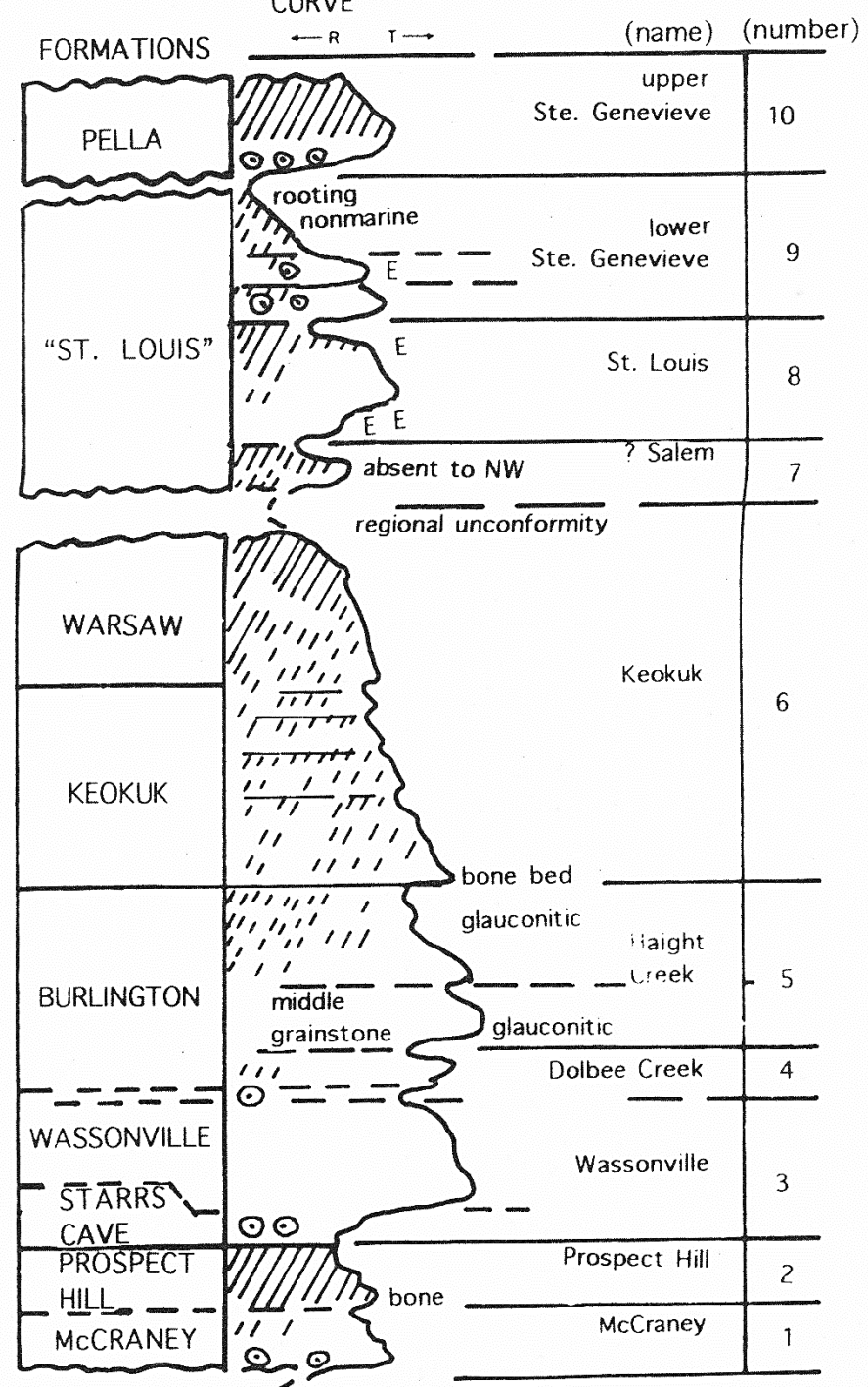
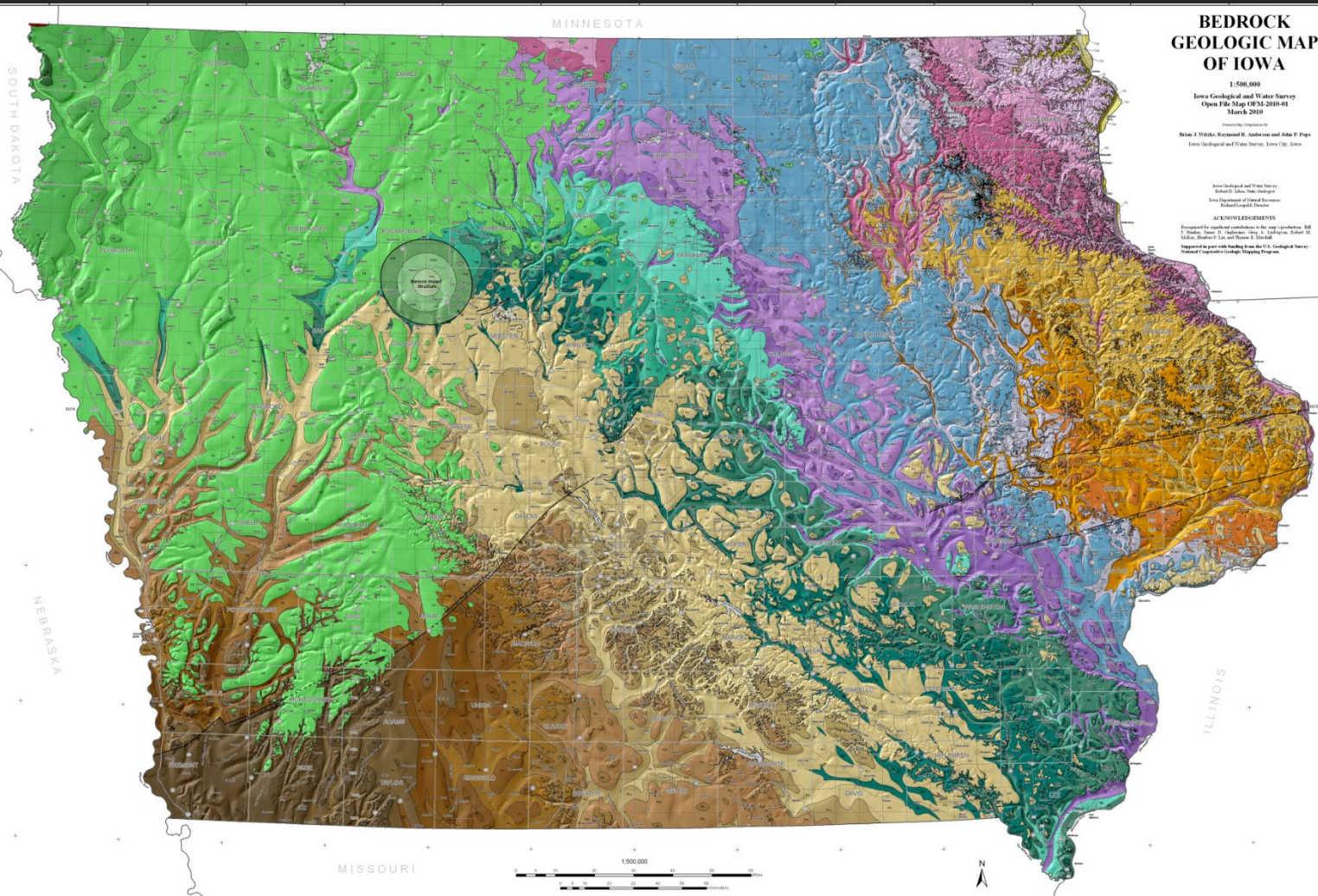
Carboniferous - Mississippian - Last major sea

323 Ma
To
358 Ma

- The stratigraphic record contains TEN Transgression-Regression (T-R) Cycles
- Oolites and sand-sized fossil fragments are abundant
 - Exceptionally preserved fossils!
- Likely similar to the Bahama Banks environment of deposition today
 - Uniformitarianism
- Is as an important groundwater reservoir for north central Iowa

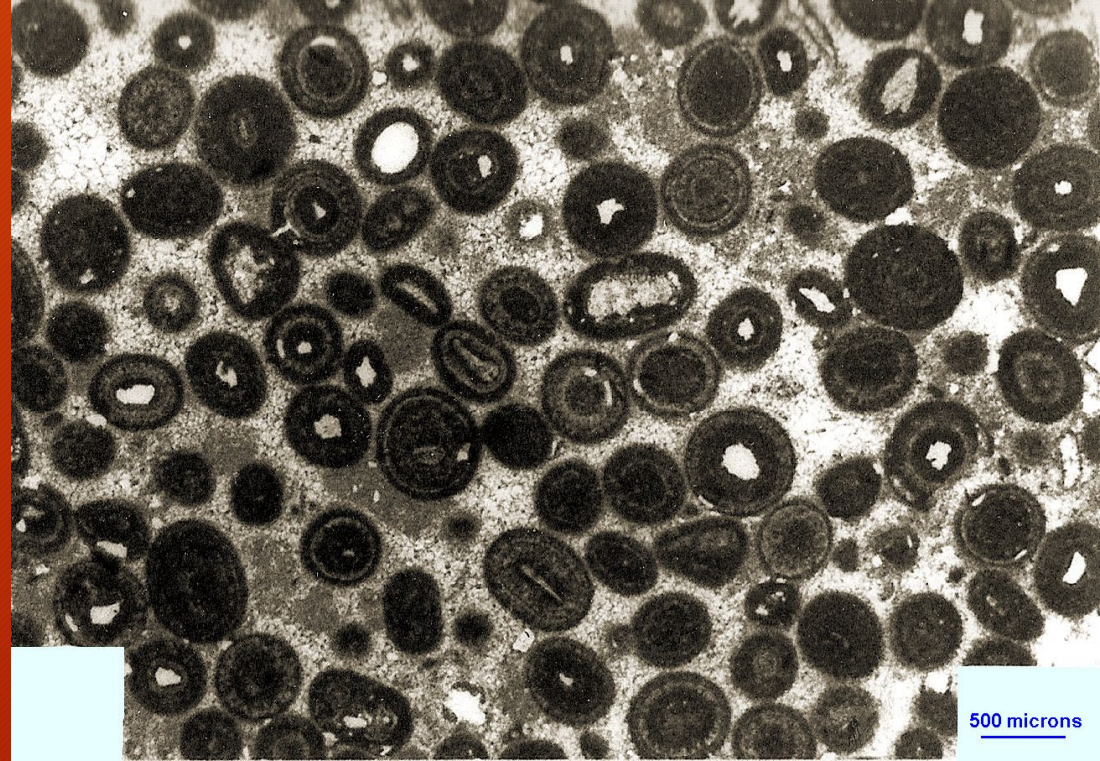


Mississippian



Starrs Cave Formation

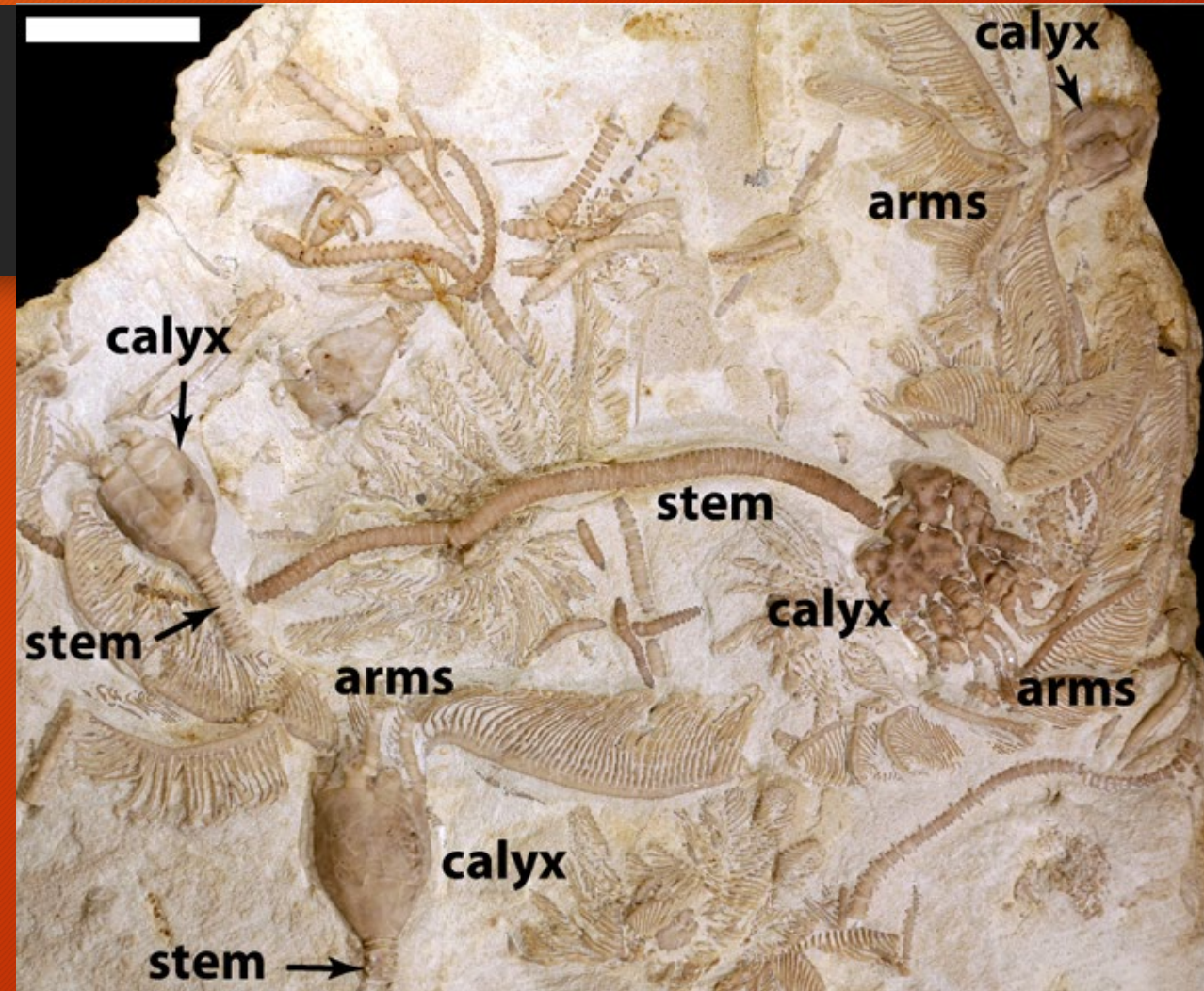
- Burlington, Iowa along Flint Creek
- Oolitic grainstone



500 microns

Burlington Formation

- One of Iowa's most well-known formations
- Excellent source for flint/chert used by native Americans
- Crinoidal limestone (packstone and grainstone)

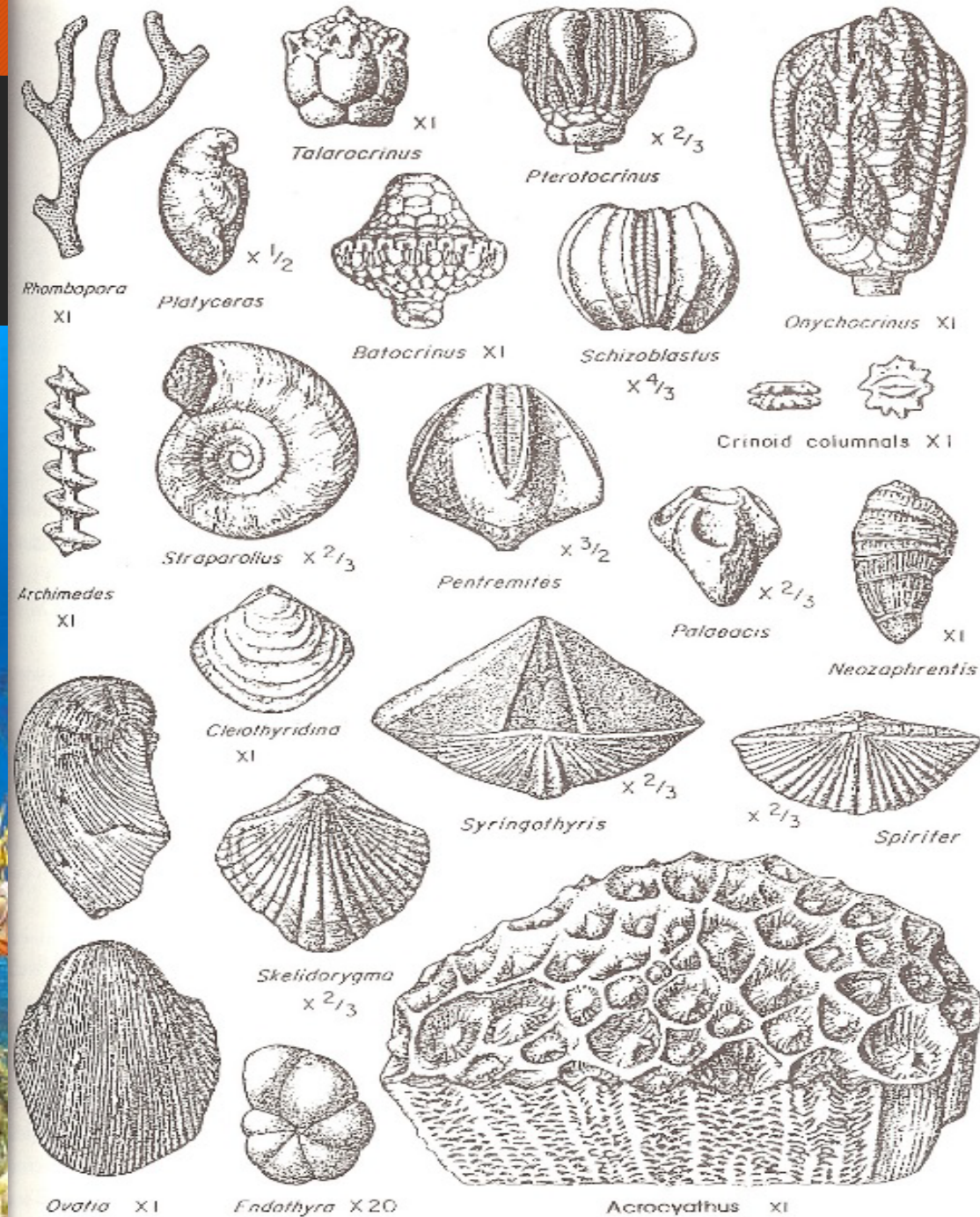


Warsaw Formation

- First described by James Hall near Warsaw, Illinois
- Southeastern Iowa
- Lower clay-rich dolostone unit yields abundant geodes



Mississippian Life





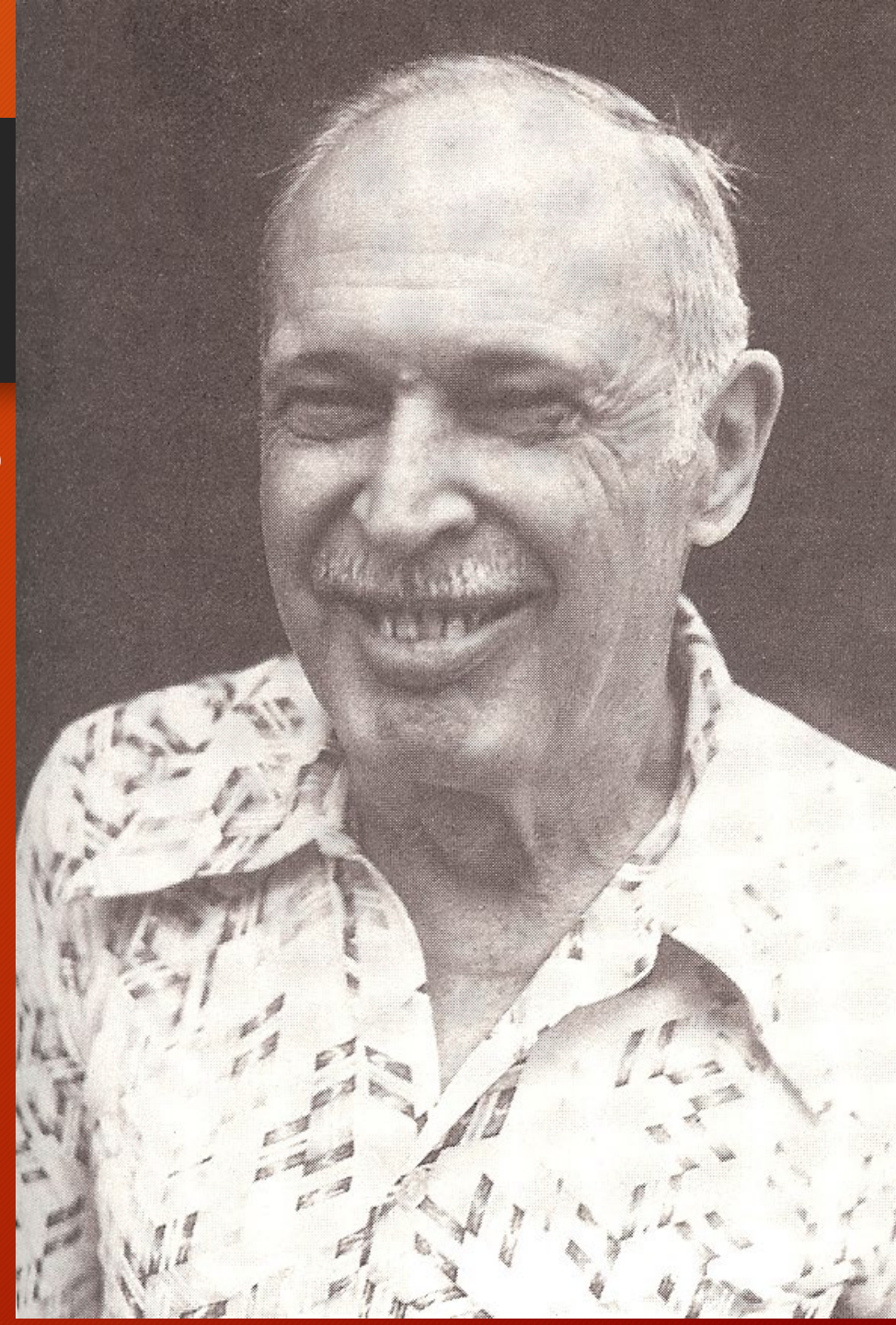
*Wachsmuth and Springer's
monograph on crinoids*

F. A. Bather

Charles Wachsmuth
1850s

Paleontologists
of all kinds!

Harrell Strimple
1970s

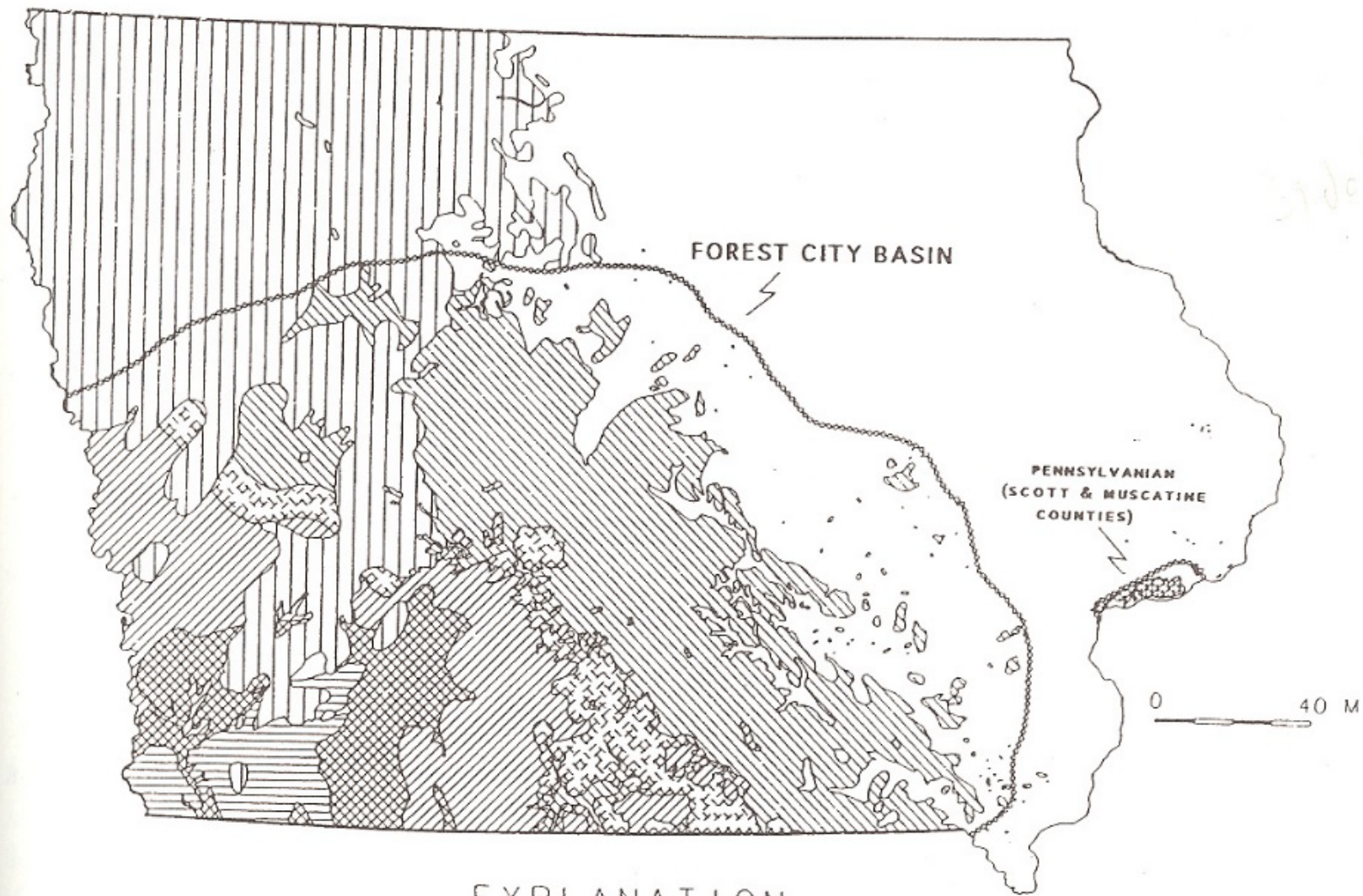


Carboniferous - Pennsylvanian - Coal swamps

232 Ma
to
298 Ma

- Coastal shorelines
 - Coal deposits
 - Cliff-forming Sandstone
 - Dolliver Memorial State Park
 - Ledges State Park
 - Wildcat Den State Park
 - Red Rock Reservoir
 - Pilot Knob County Park
- Deltas





EXPLANATION

- | | | |
|----------------------|-----------------------|-----------------------------|
| Cretaceous System | Missouri Supergroup | Morrow Supergroup |
| □ undifferentiated | ▨ undifferentiated | ▩ Caseyville and Spoon Fms. |
| Pennsylvanian System | Des Moines Supergroup | □ Older Paleozoics |
| Virgil Supergroup | ▧ Marmaton Group | |
| ▨ Wabaunsee Group | ▩ Cherokee Group | |
| ▩ all other units | | |

BEDROCK GEOLOGIC MAP OF IOWA

1:500,000

Iowa Geological and Water Survey
Open File Map OFM-2010-01
March 2010

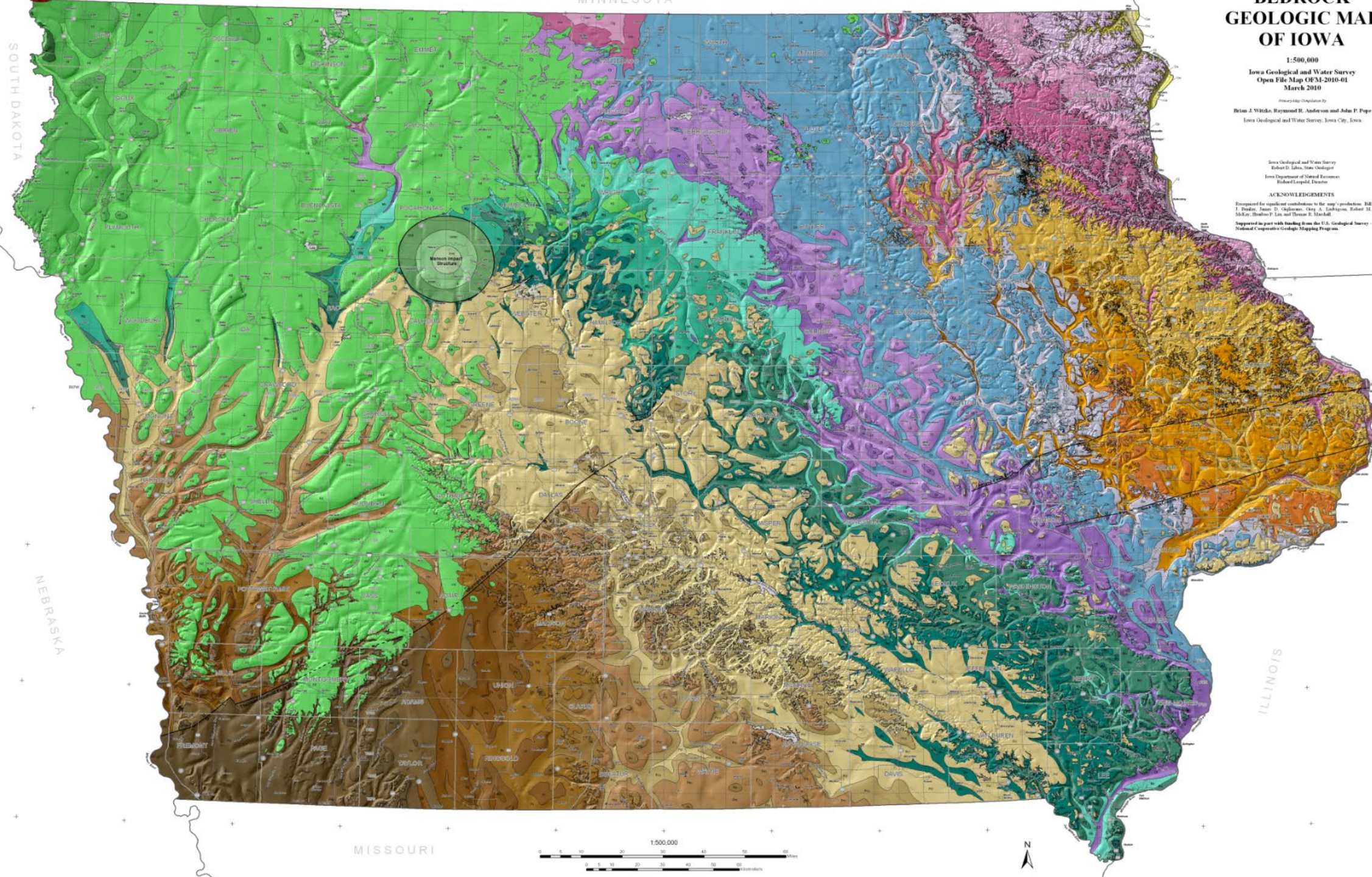
Primary Map Compilation by

Brian J. Witko, Raymond R. Anderson and John P. Pope
Iowa Geological and Water Survey, Iowa City, Iowa

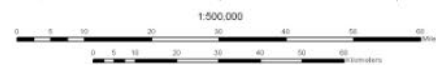
Iowa Geological and Water Survey
Robert D. Liles, State Geologist
Iowa Department of Natural Resources
Richard Leopold, Director

ACKNOWLEDGEMENTS

Discussed for significant contributions to the map's production: Bill J. Poulter, James D. Caghaman, Greg A. Lindquist, Robert M. Miller, Thomas P. Liu, and Thomas E. Marshall.
Supported in part with funding from the U.S. Geological Survey's National Cooperative Geologic Mapping Program.



MISSOURI



ILLINOIS

SOUTH DAKOTA

NEBRASKA

Stratigraphy, petrology, and paleogeography
of the upper portion of the
Cherokee Group
(Middle Pennsylvanian),
eastern Kansas and northeastern Oklahoma

Robert L. Brenner

Geology Series 3 1989
Kansas Geological Survey



Cherokee Group

INTEGRATIVE STRATIGRAPHY Concepts and Applications

Robert L. Brenner
Department of Geology
University of Kansas
Lawrence, Kansas

Timothy R. McHugh
Kansas Geological Survey
Lawrence, Kansas

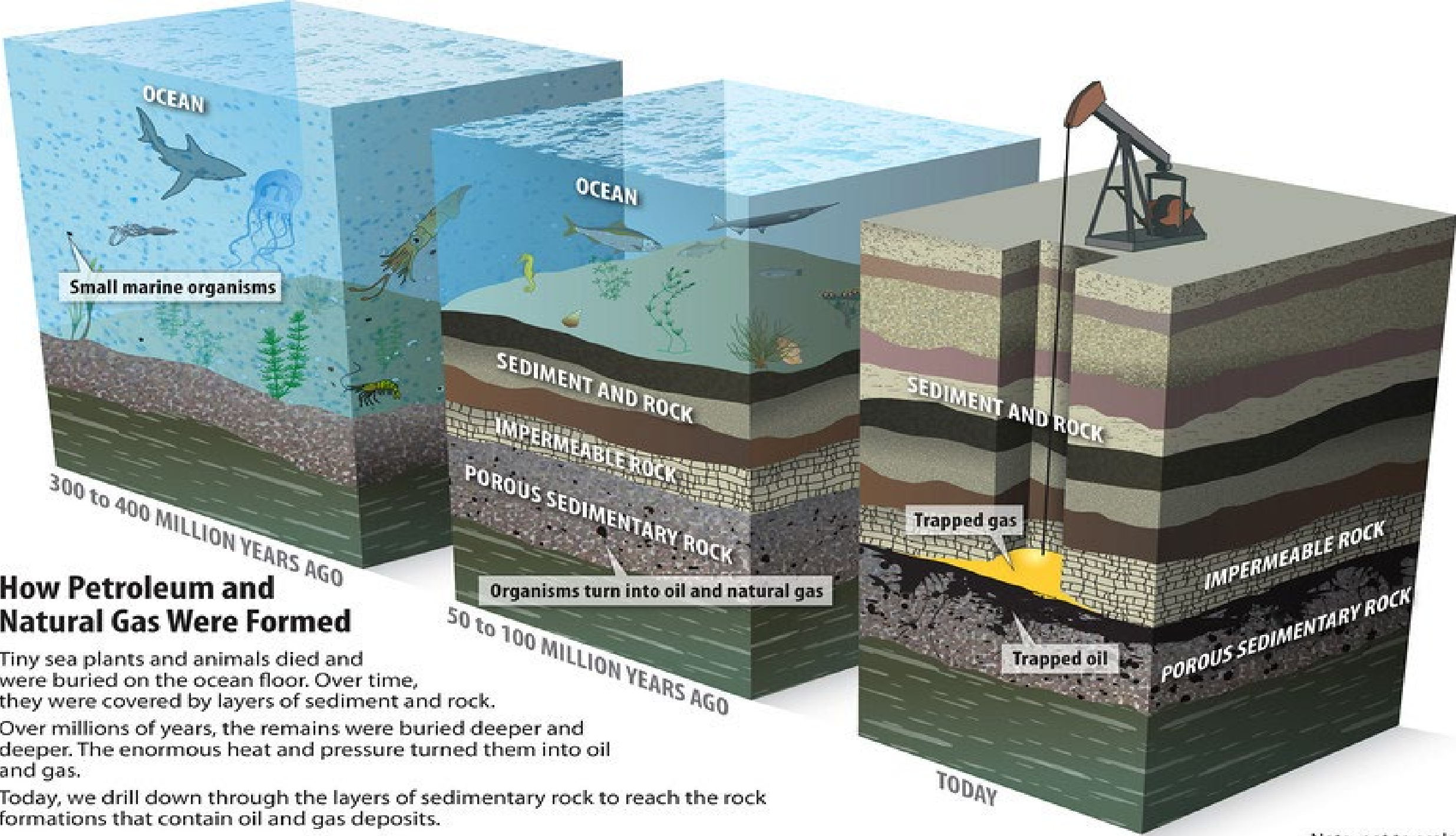


Published by the Kansas Geological Survey, Lawrence, Kansas, 1989

SUPERGROUP		GROUP	FORMATION	COALS	SERIES
VIRGIL	WABAUNSEE			Nyman Elmo Nodaway*	VIRGILIAN
	SHAWNEE				
	DOUGLAS			unnamed	
MISSOURI	LANSING				MISSOURIAN
	KANSAS CITY				
	BRONSON			Ovid	
DES MOINES	MARMATON	LOST BRANCH			DESMOINESIAN
		NOWATA			
		ALTAMONT			
		BANDERA		Lonsdale	
		PAWNEE			
		LABETTE		Mystic* Marshall/ Lower Mystic	
		STEPHENS FOREST			
		MORGAN SCHOOL		Summit	
		MOUSE CREEK			
		SWEDE HOLLOW		Mulky Bevier* Wheeler* Whitebreast* Carruthers*	
CHEROKEE	SPOON FM.	FLORIS		unnamed* Laddsdale*	?
		KALO		Cliffland* Blackoak*	
		KILBOURN		unnamed*	
MORROW		CASEVILLE		Wyoming Hill* unnamed Wildcat Den	MORROWAN

Lepidodendron





How Petroleum and Natural Gas Were Formed

Tiny sea plants and animals died and were buried on the ocean floor. Over time, they were covered by layers of sediment and rock. Over millions of years, the remains were buried deeper and deeper. The enormous heat and pressure turned them into oil and gas.

Today, we drill down through the layers of sedimentary rock to reach the rock formations that contain oil and gas deposits.

Note: not to scale

Types of Coal

- Anthracite
- Bituminous
- Sub-Bituminous
- Lignite



Iowa Coal

- Sub-Bituminous to Bituminous
- High ash and sulfur content
 - Ash results from sediment (impurities) that were washed into the swamps
 - Sulfur occurs as pyrite (FeS_2)
- Iowa coal is not considered a natural resource because it is not economically feasible to extract.



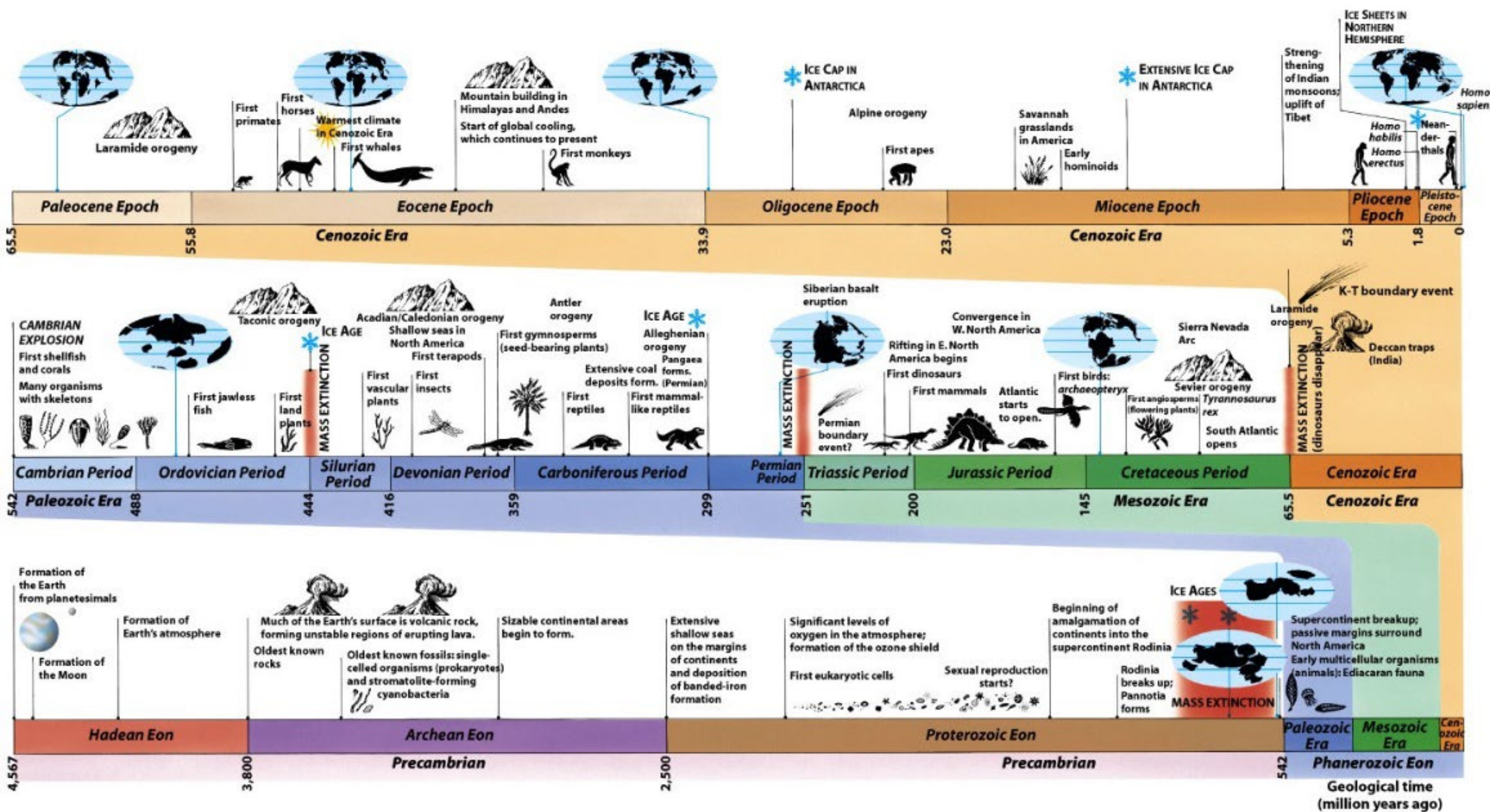
Mesozoic - Evaporite Deposits

Last of the Shallow Inland Seas

66 Ma
to
232 Ma

66
to
252

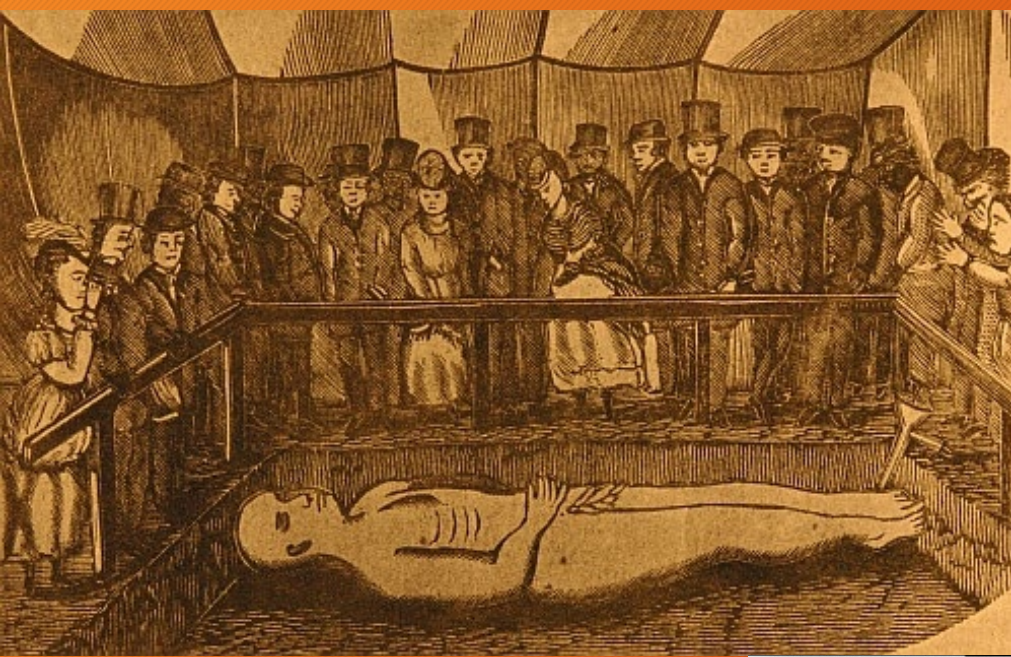
- Massive weathering and erosion
 - Large unconformity between the Mesozoic and Cenozoic
 - Iowa has no Permian or Triassic rock record!
- Fort Dodge Formation contains thick evaporate deposits of rock gypsum with minor red, green, and gray clastic rocks.
- Manson Impact Structure at 73.8 Ma



Fort Dodge Formation

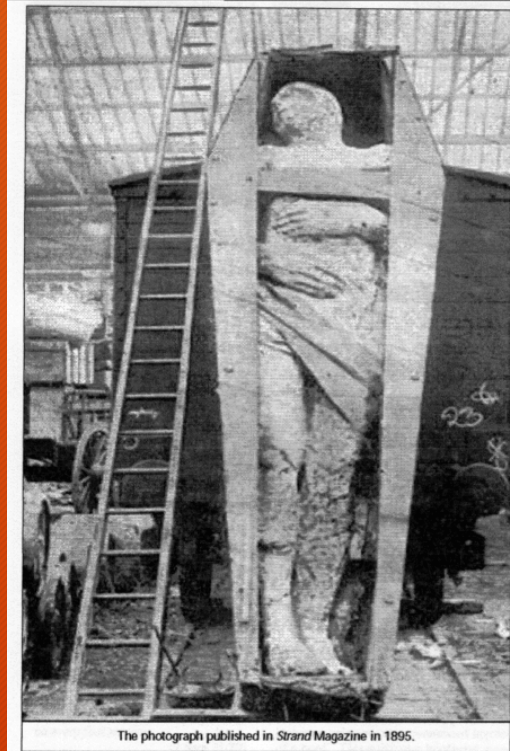
- First thought to be Permian, because of association with western USA gypsum and 'red-bed' deposits
- Jurassic - based on fossil plant remains
- Fort Dodge Gypsum
 - $\text{CaSO}_4 \cdot \text{H}_2\text{O}$





The Cardiff Giant

- 1866 - George Hull visits his sister in Ackley, Iowa and goes to church
- 1868 - One dark night the Gypsum Giant is buried on his Brother-in-laws farm near Cardiff, New York
- 1869 - The Giant was 'discovered', a tent was set up, droves of people came to see the giant @ 50 cents a person
- James Hall - The most remarkable object yet brought to light in this country'

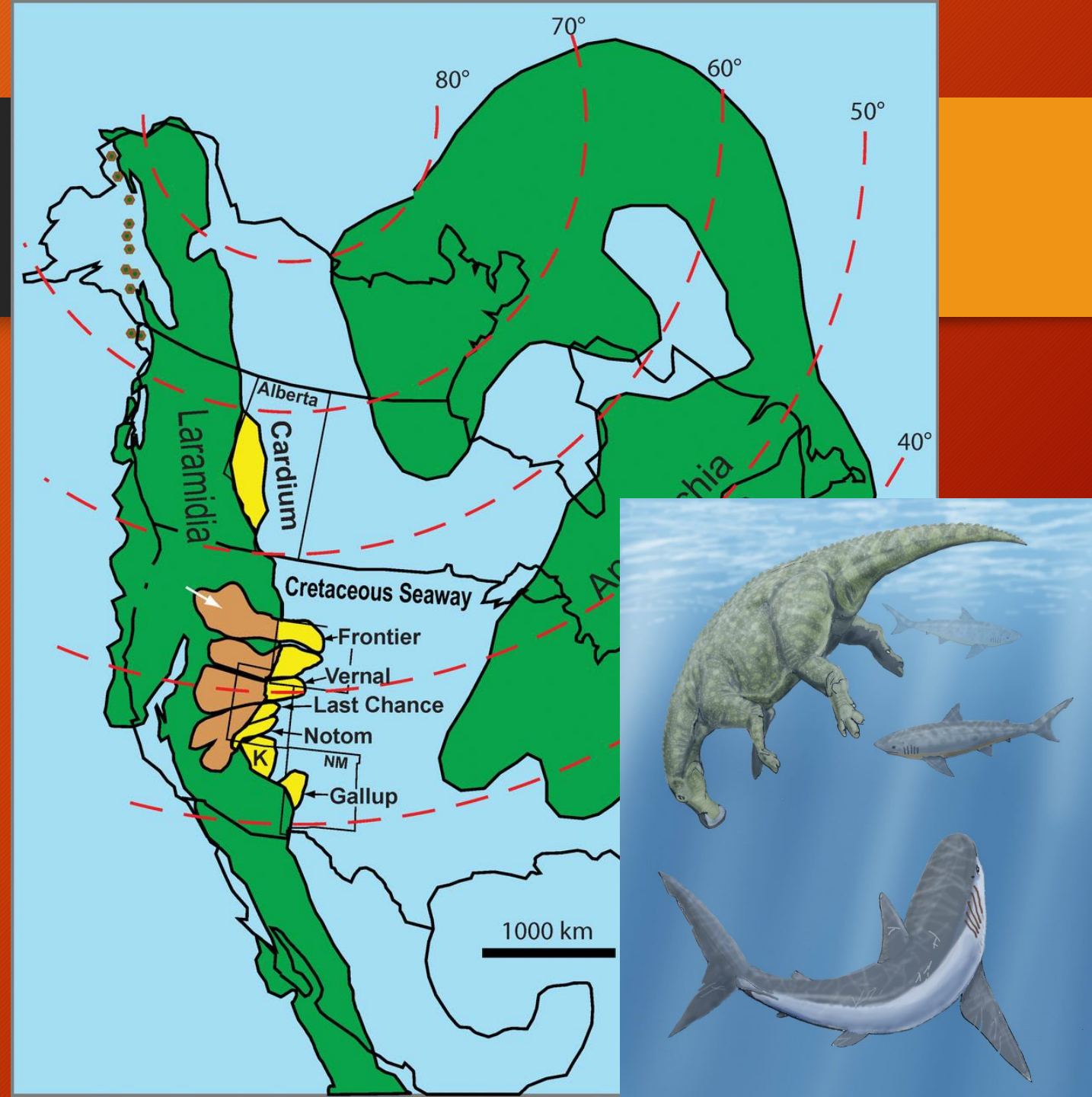


The photograph published in Strand Magazine in 1895.

“People are gullible”
- George Hull

Cretaceous

- Dakota Formation
 - Western Iowa
 - Sandstone, mudstone, conglomerate
 - Fluvial environments



THE MANSON IMPACT STRUCTURE

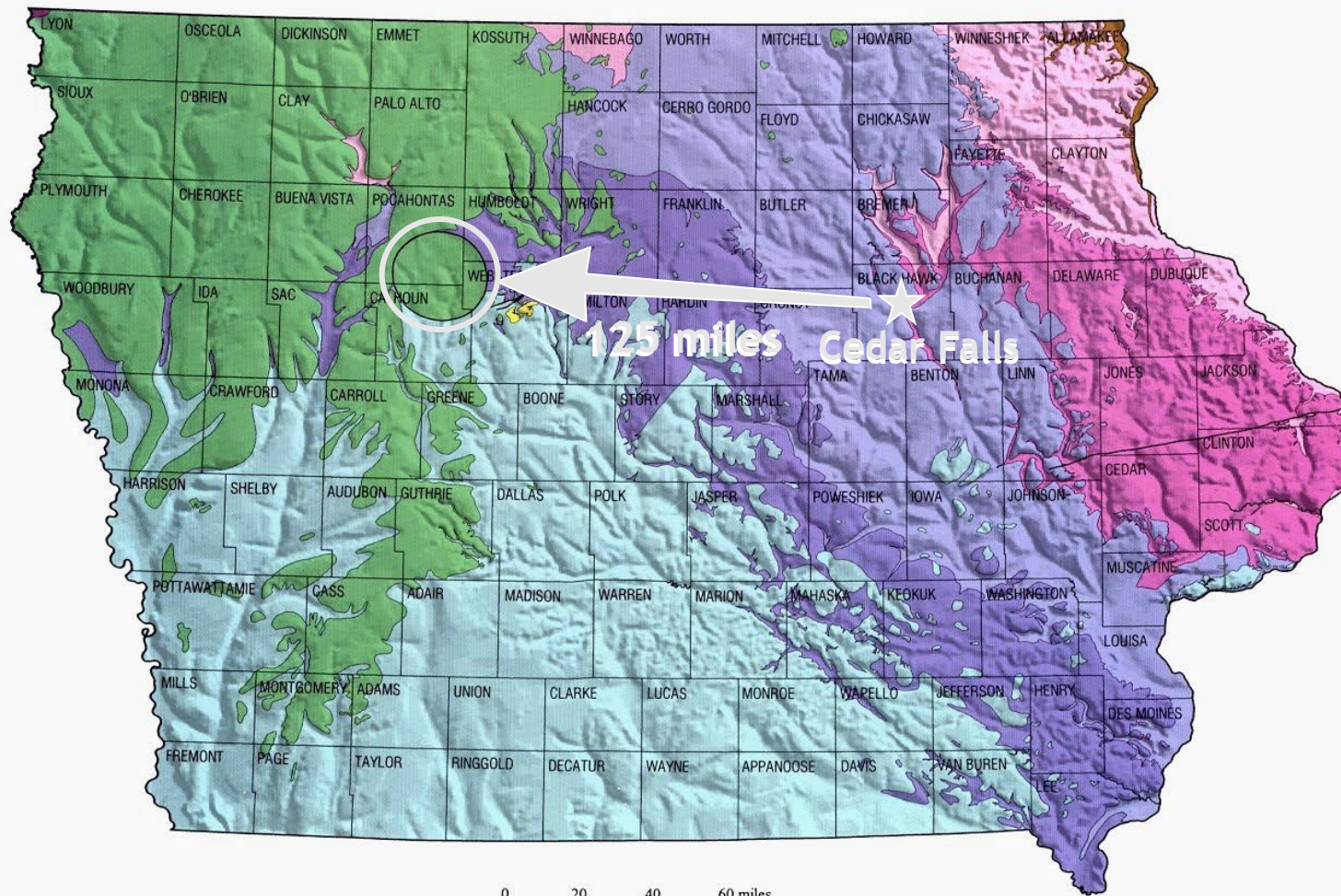
IOWA'S GREATEST CATASTROPHE

Viva Ray Anderson



BEDROCK GEOLOGIC MAP OF IOWA

1998



Geologic Systems

Age of rocks in Iowa
(million years before present)

■ **Cretaceous**
(74–102)

■ **Jurassic**
(160)

■ **Pennsylvanian**
(298–320)

■ **Mississippian**
(325–353)

■ **Devonian**
(355–385)

■ **Silurian**
(415–435)

■ **Ordovician**
(439–505)

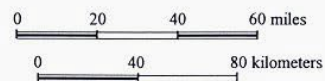
■ **Cambrian**
(505–530)

■ **Precambrian**
(600?–2,910+)

Fault trace

 Manson Impact Structure

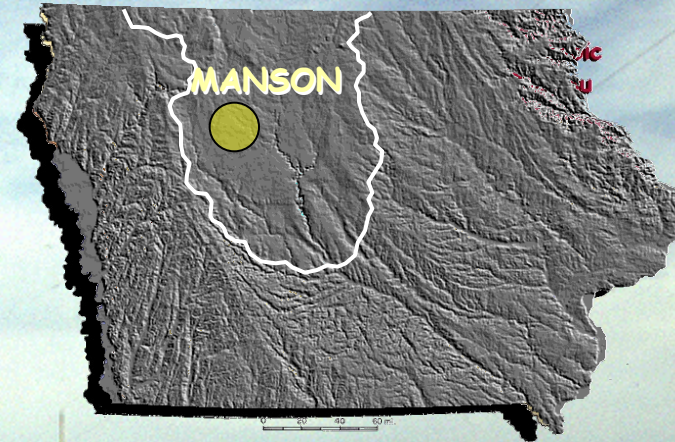
Shading highlights relief on the bedrock surface.



Iowa Department of Natural Resources

Geological Survey Bureau • 109 Trowbridge Hall • Iowa City, Iowa 52242-1319

“Scenic Overview” of the Manson Impact Structure



The facies of the cuttings also is abnormal, especially in the appearance of conglomerate and in the large amount of arkosic material. In some aspects they are strikingly similar to those of the De Witt well below the Saint Peter sandstone, and to similar sections at Maquoketa and Preston, which the writer has interpreted as the fill of deep erosion channels cut in rocks of the Prairie du Chien during the interval preceding the deposit of the Saint Peter sandstone.

The exceptional character and thickness of the shales and arkose of the Manson well are explainable by a like hypothesis—the fill with continental deposits, and finally with marine sediments also, of a valley of erosion. The depth of the valley, 300 feet deeper than that of the Mississippi in northeastern Iowa, is notable. The arkosic material of the fill suggests that the headwaters of the river worked in the igneous rocks of the states bordering Iowa on the north.

The deposits themselves, so far as the cuttings reveal them, do not appear to offer conclusive evidence as to their age, whether they were laid at the close of the long erosion interval preceding the deposit of the Pennsylvanian or of that preceding the Cretaceous. The fact that Manson is located less than 5 miles west of the provisional eastern border of the Cretaceous would preclude the expectation of finding there any great thickness of normal marine sedimentary deposits of Cretaceous age, but not the fill of a deep pre-Cretaceous valley.

DEEP WELLS OF IOWA (A Supplementary Report)

by

W.H. NORTON

WITH A CHAPTER ON

Well Water Recessions in Iowa

by

James H. Lees

WITH A TABLE OF IOWA TOWNS GIVING

Municipal Water Supplies



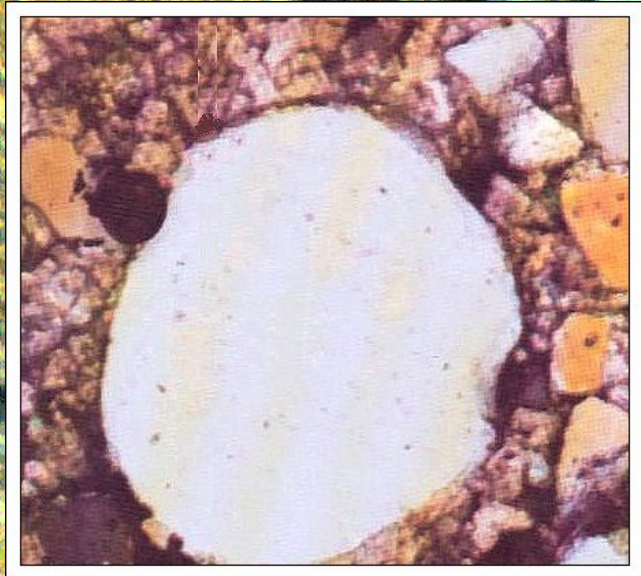
SKYLAB photograph of the Manson area

June 1978



(limits of the structure
shown by black line)





PDFs in
Quartz Grains

Manson 1-A core

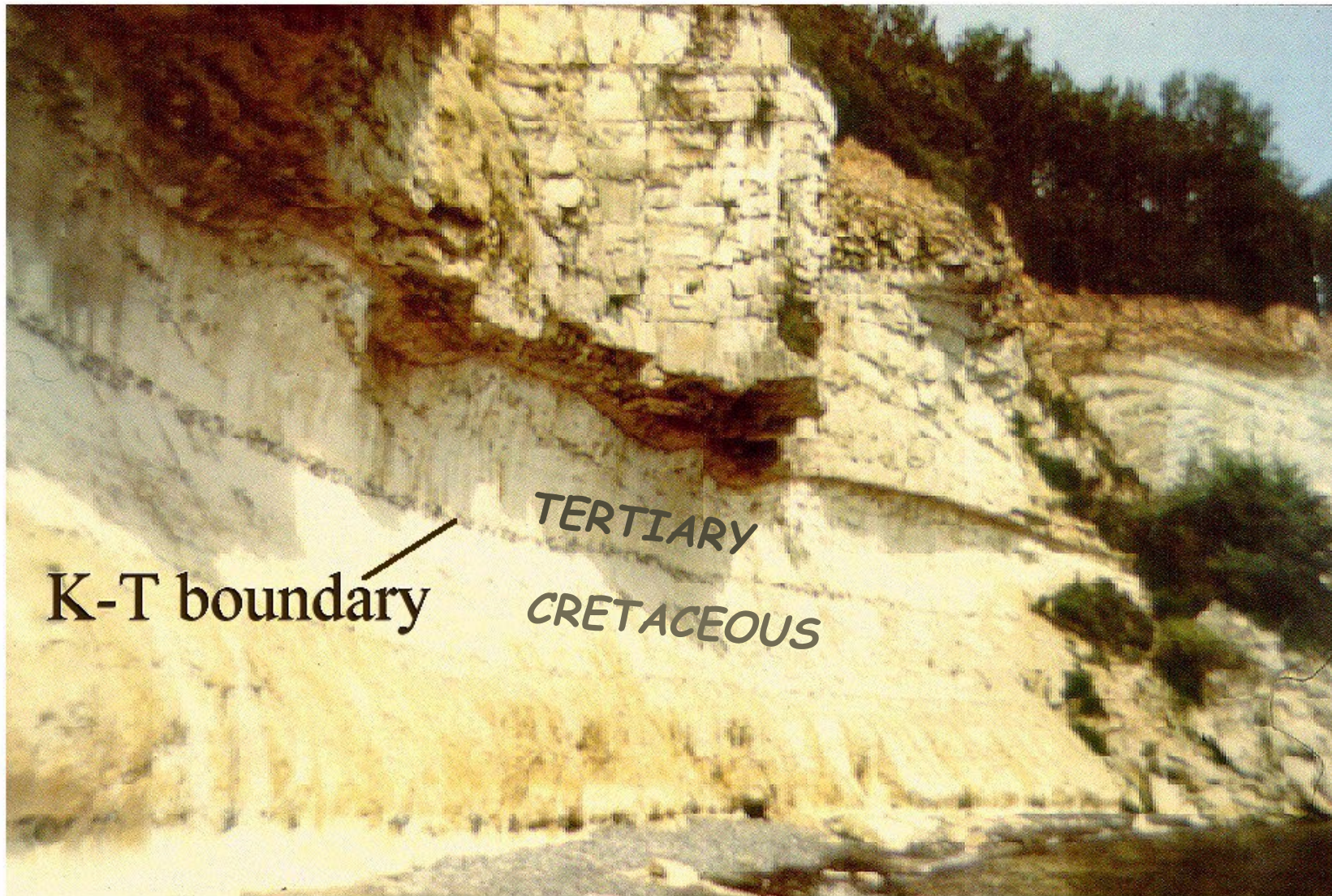
1 mm



1980



The late Luis Alvarez, a physicist, and his geologist son, Walter, examine a clue to the dinosaurs' demise.



K-T boundary

TERTIARY

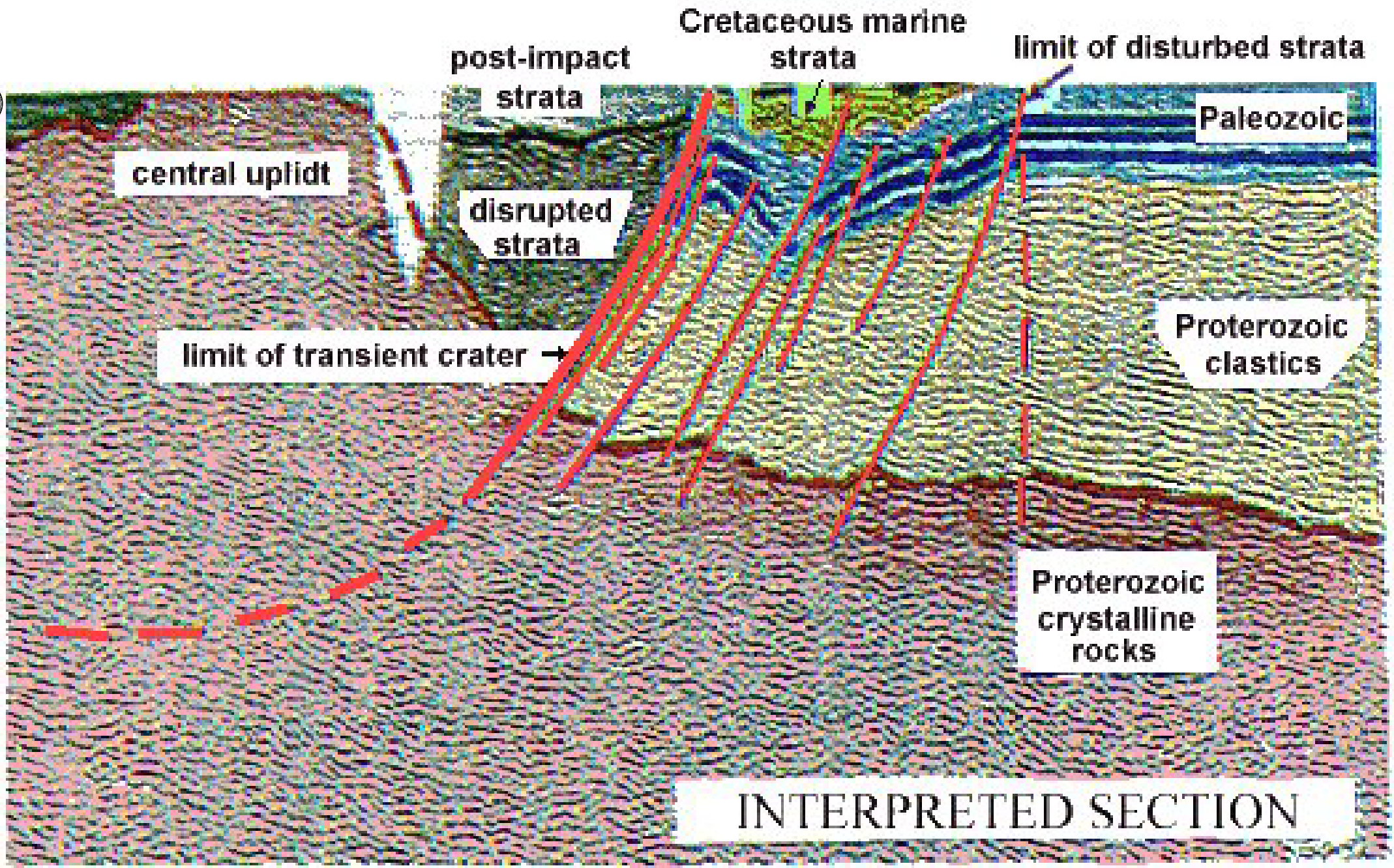
CRETACEOUS

Stevens Klint, Denmark

TWO-WAY TRAVEL TIME (SEC)



0.5
1.0
1.5
2.0



Seismic data courtesy of Amoco Production Co.

Manson
100 Ma - 500,000

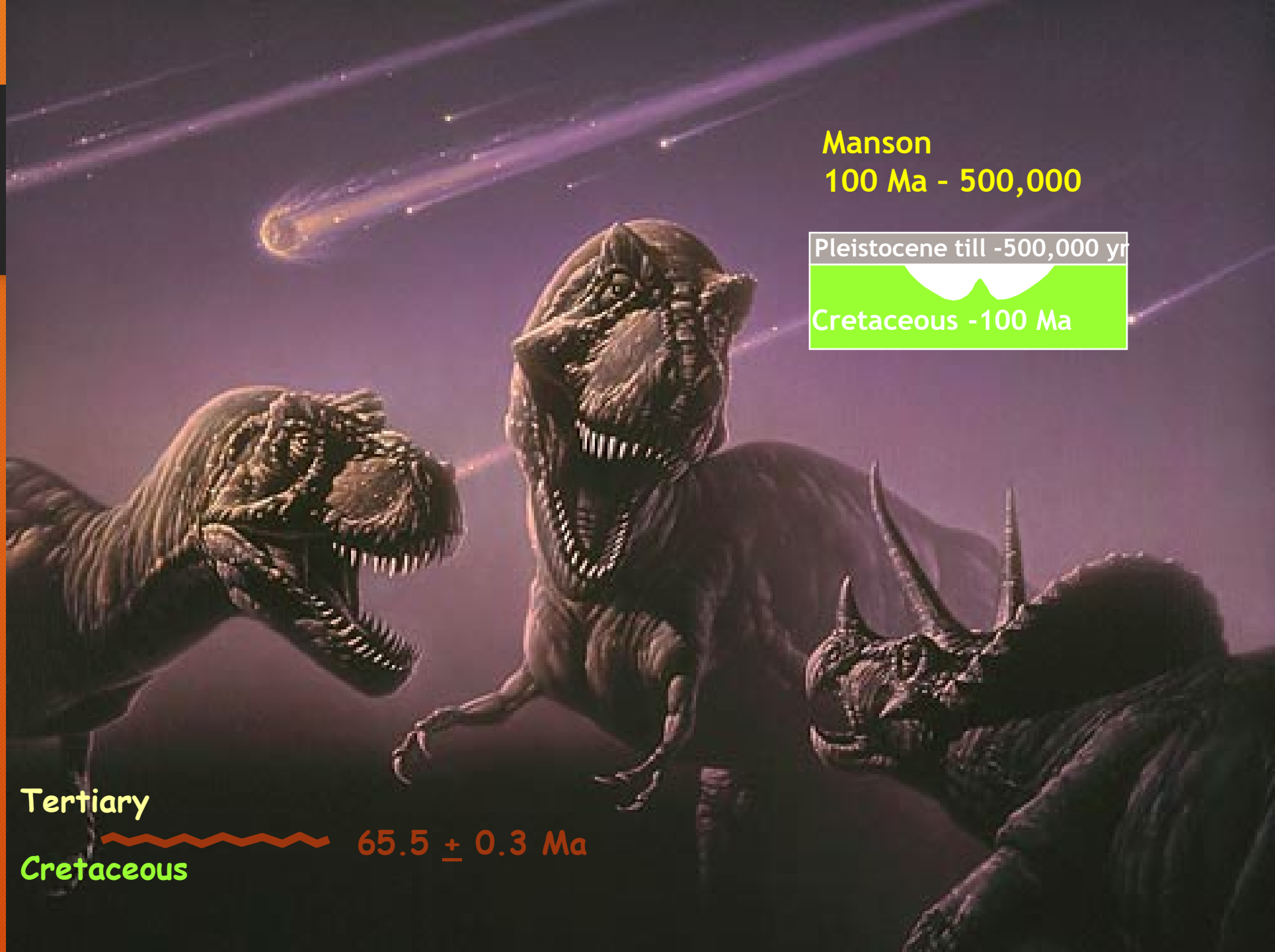
Pleistocene till -500,000 yr

Cretaceous -100 Ma

Tertiary

Cretaceous

65.5 ± 0.3 Ma

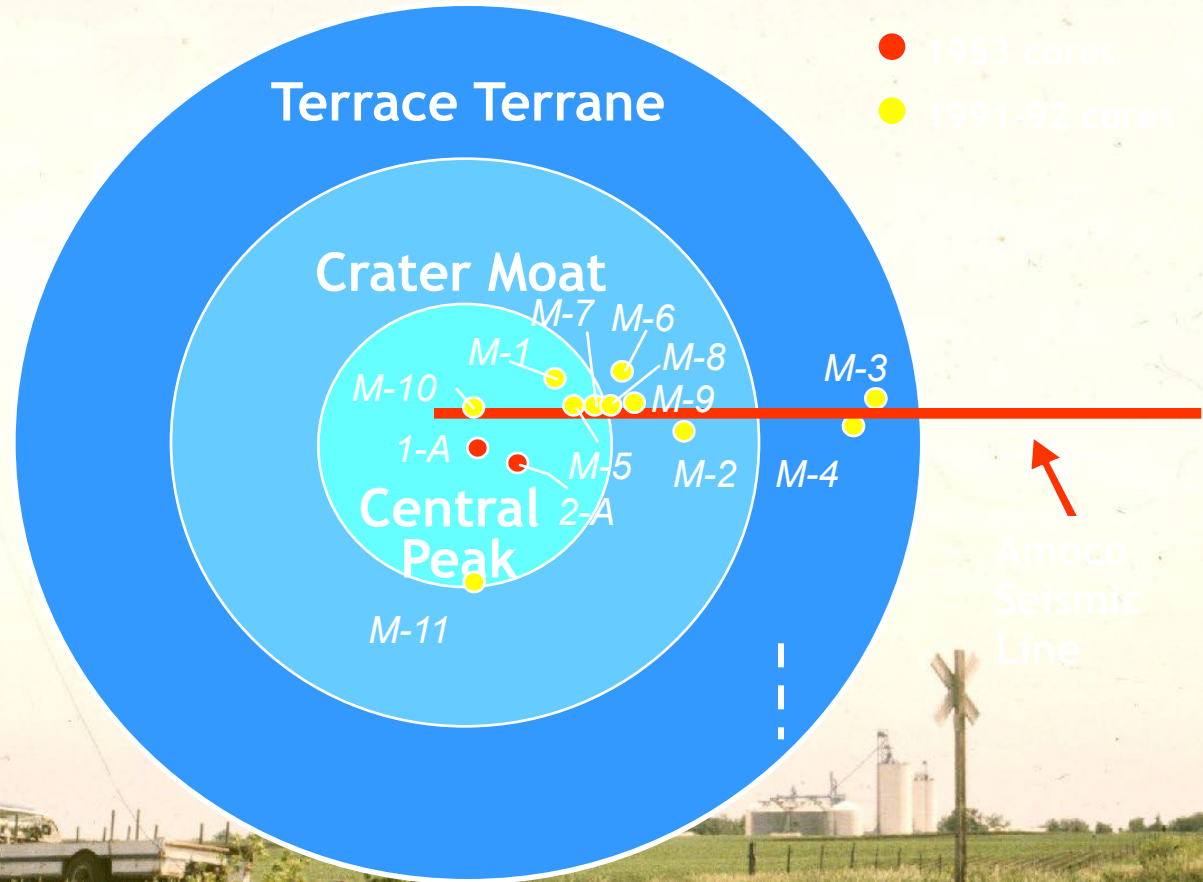
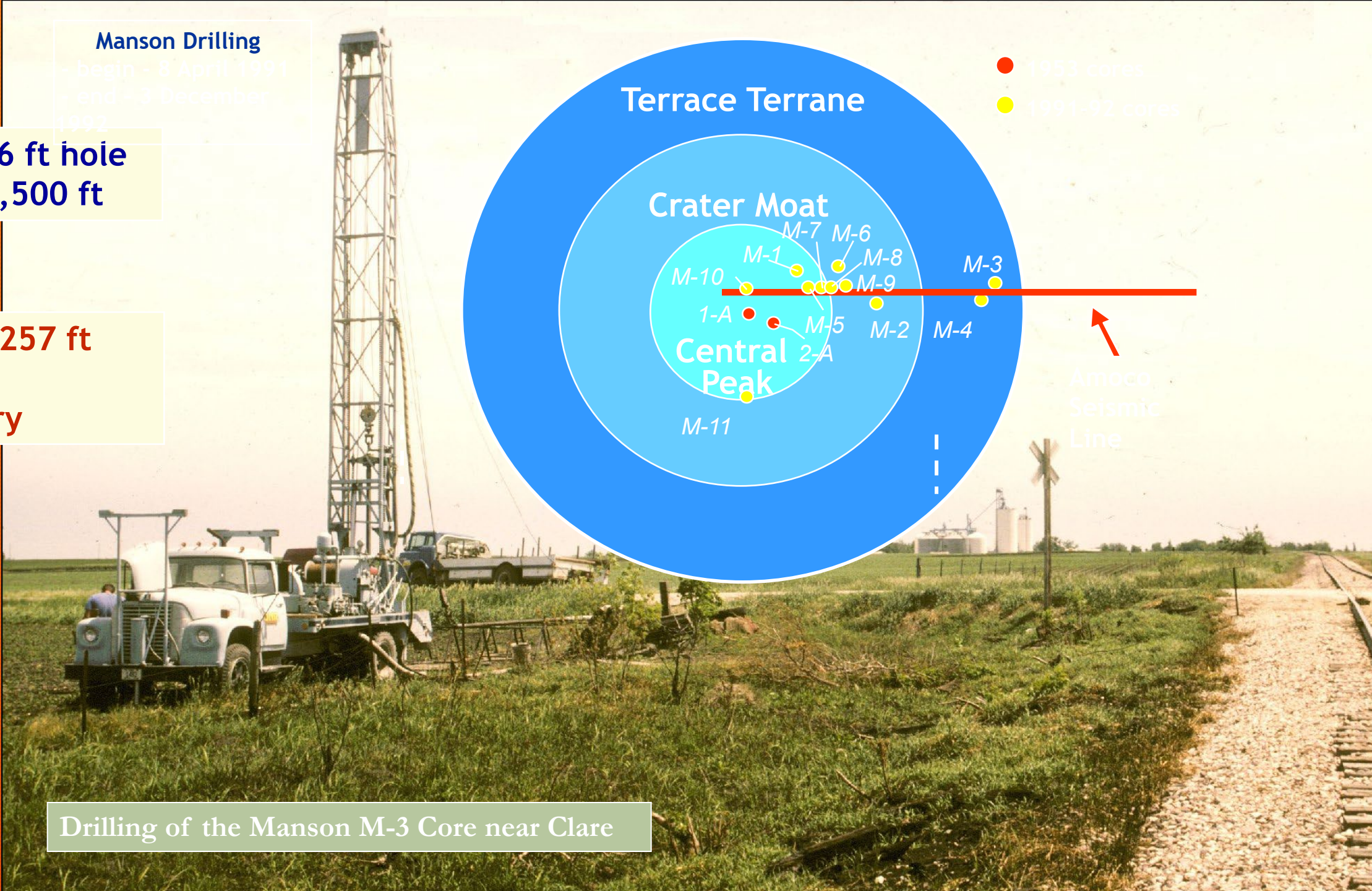


Manson Drilling

- begin - 8 April 1991
- end - 3 December 1992

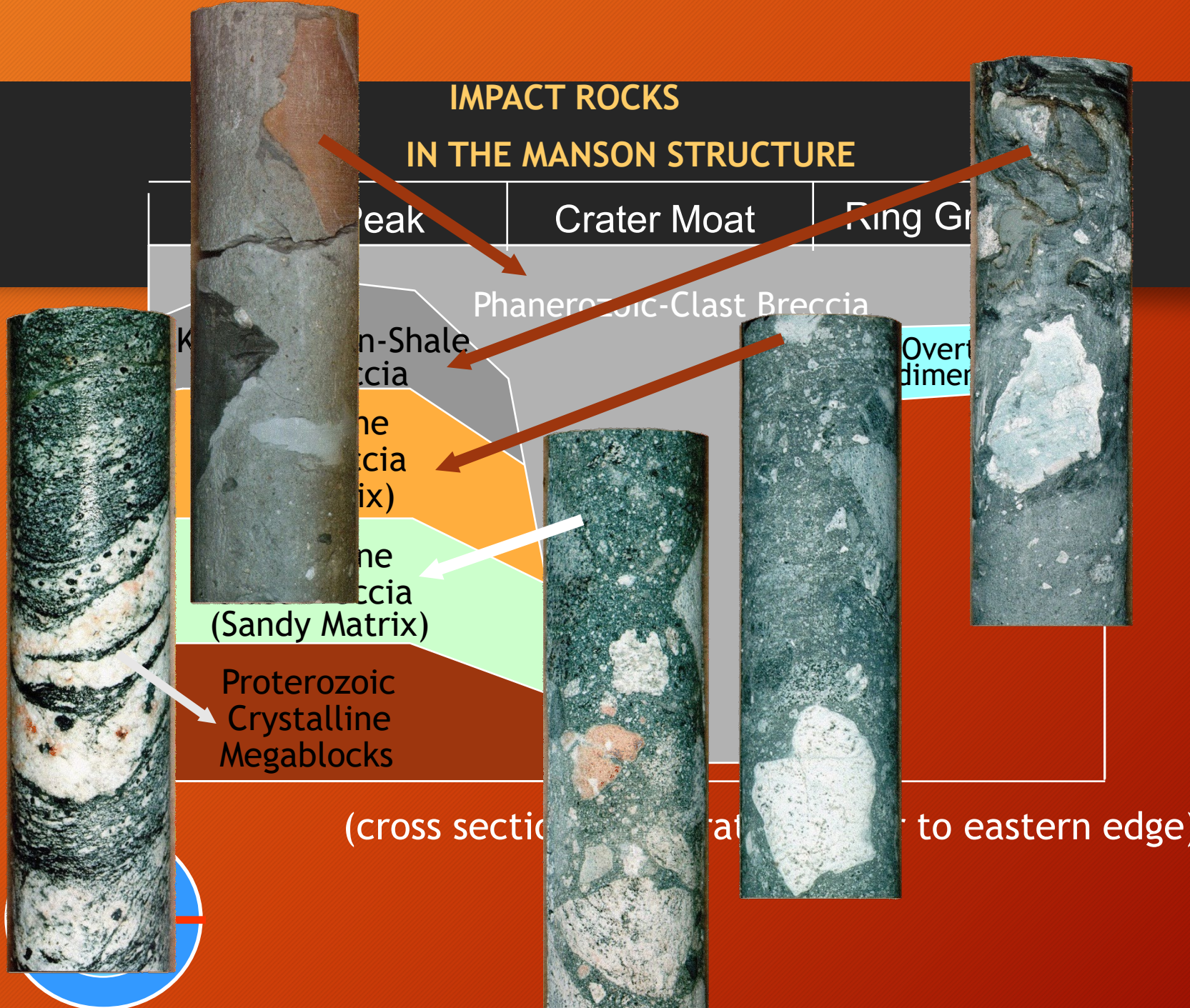
**drilled 4,826 ft hole
- rock-bit 1,500 ft**

**collected 3,257 ft
core
98% recovery**



Drilling of the Manson M-3 Core near Clare

IMPACT ROCKS IN THE MANSON STRUCTURE



Peak Crater Moat Ring Gr

Phanerzoic-Clast Breccia

n-Shale
cia

ne
cia
ix)

ne
ccia
(Sandy Matrix)

Proterozoic
Crystalline
Megablocks

Overdimensional

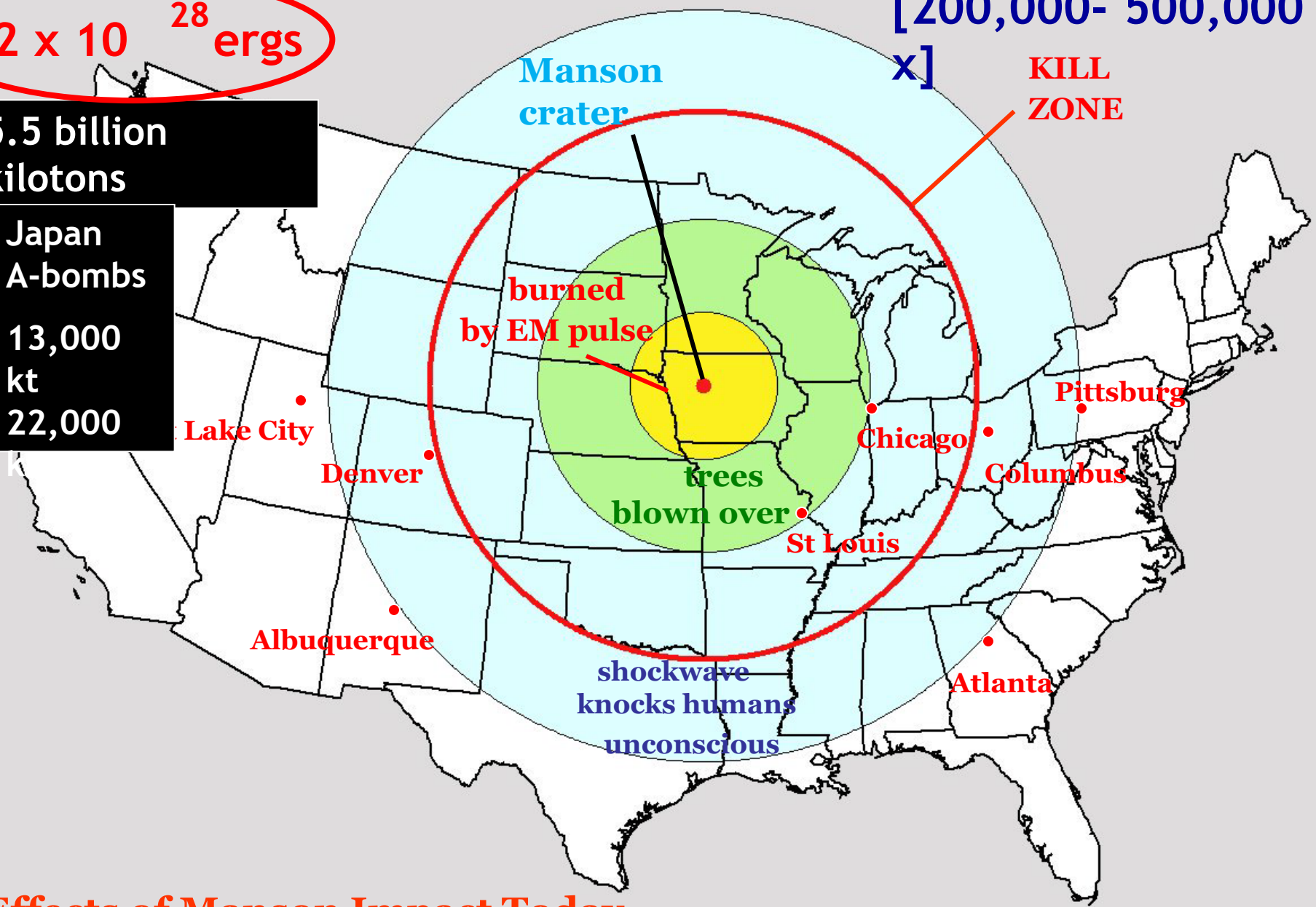
(cross section from crater to eastern edge)

2.2×10^{28} ergs

5.5 billion kilotons

Japan A-bombs
13,000 kt
22,000

[200,000- 500,000 x]



Effects of Manson Impact Today



BILL BRYSON

*A Short History of Nearly Everything

Author of A Walk in the Woods and In a Sunburned Country

