

Minerals in Arizona through Geologic History

Jan C. Rasmussen, Ph.D.

Consulting Geologist, Tucson

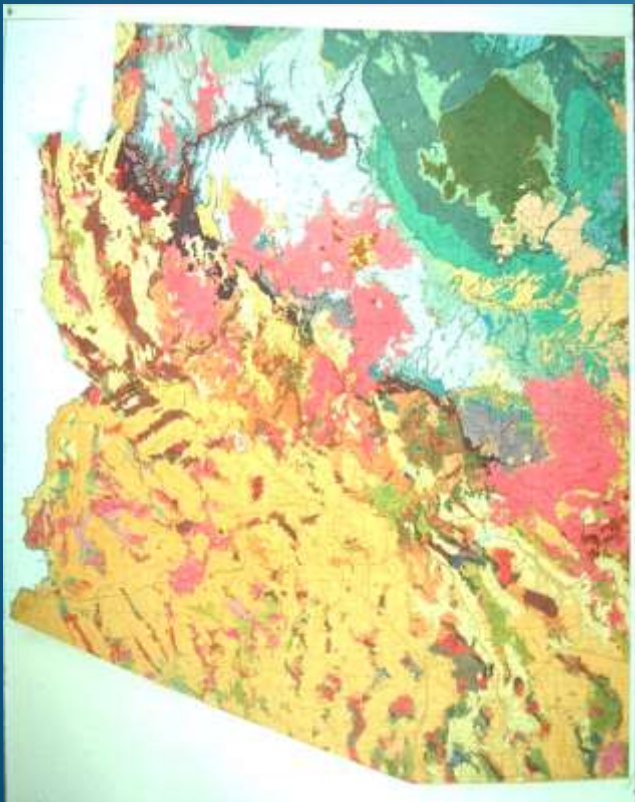
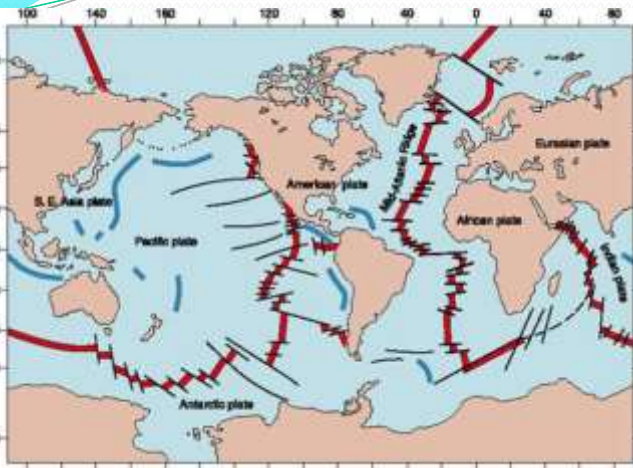
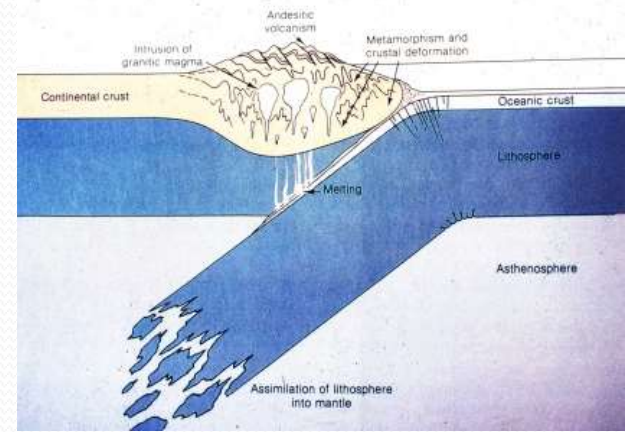


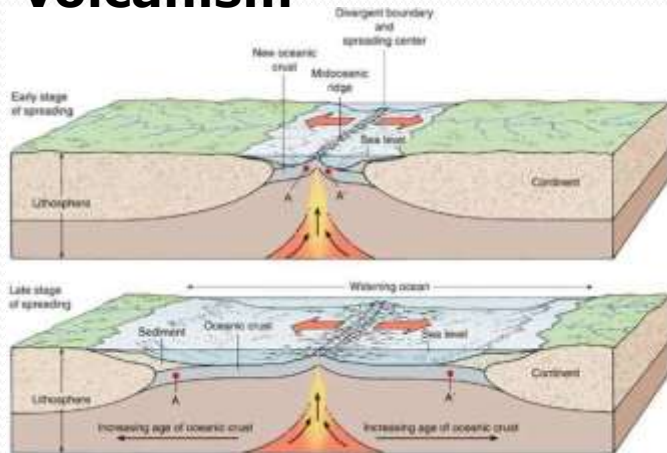
Plate Tectonics



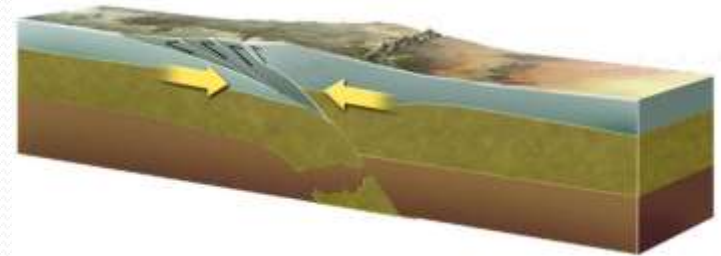
**Paleozoic =
West-dipping
subduction,
Volcanoes,
Appalachian
Mountains**



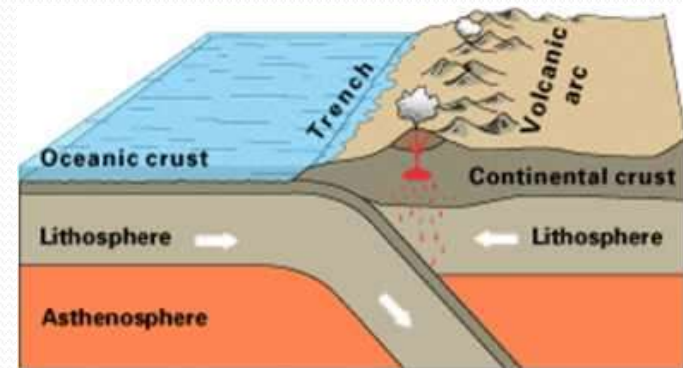
**Sea floor spreading
and mid-ocean ridge
volcanism**



**Continent-
continent
collision and
very tall
mountains**

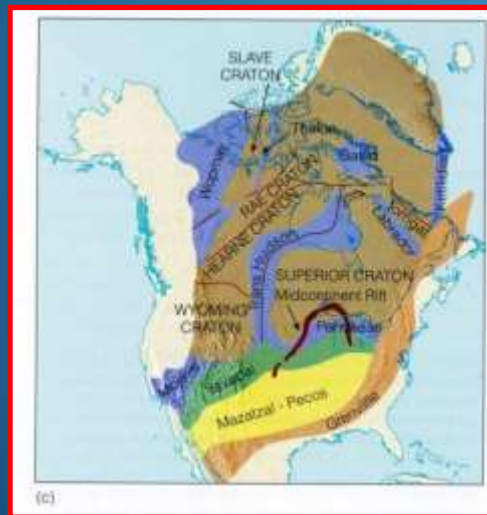
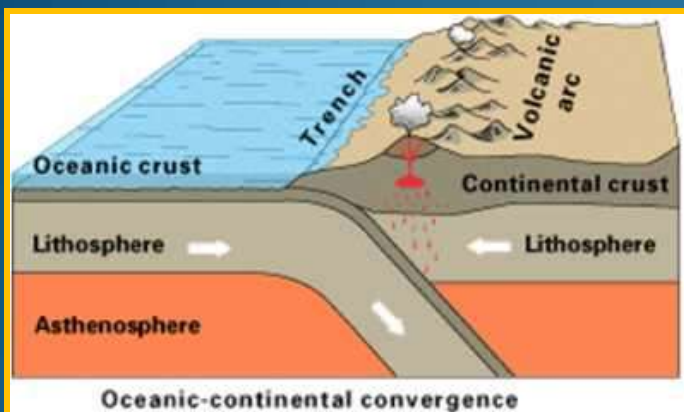


**Mesozoic-
Cenozoic
east-dipping
subduction,
Volcanoes,
Mountains**



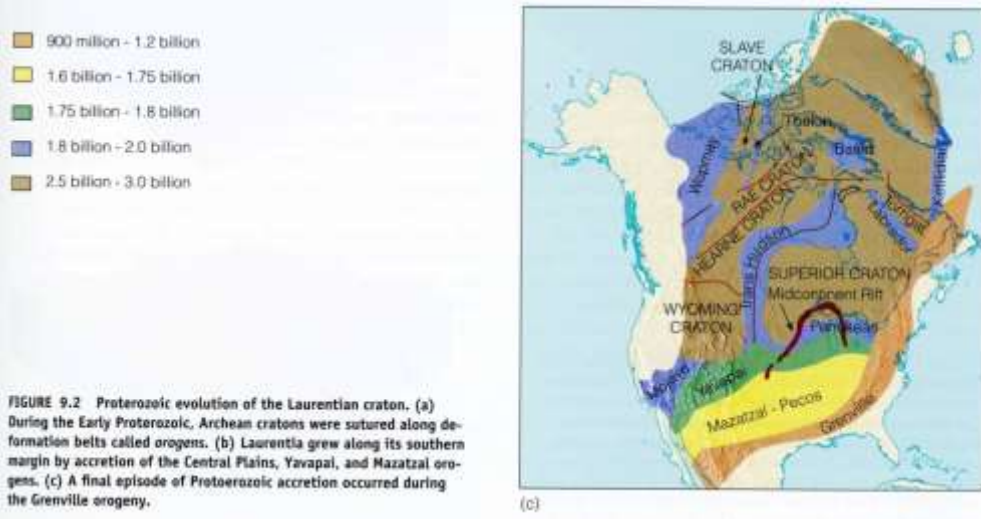
Oceanic-continental convergence

Orogenies in Arizona



Orogeny	Orogenic Phase	Age (Ma)	Age (period)	Arizona Mineralism	Alkalinity	Resources	Mining districts
San Andreas	Basin & Range	13-0	Latest Tertiary	anhydrous basaltic volcanism	Metalum. Alkalic	Sand, gravel, salt, zeolites, gypsum	San Francisco volcanic field, San Carlos olivine, Emerald Isle exotic Cu
Galiuro	Late (Whipple)	18-13	Late Tertiary	volcanics & local epizonal stocks	Metalum. inous Alkalic	Cu-Au-Ag in veins; epithermal Au-Ag veins	Oatman, Mammoth, Rowley, Swansea
	Middle (Dahl)	28-18	Mid-Tertiary	alkali-calcic ignimbritic volcanics & plutons	Metaluminous Alkali-calcic	Pb-Zn-Ag F veins; replace.; epithermal	Silver (Red Cloud), Castle Dome, Stanley, Aravaipa
	Early (South Mountain)	30-22	Mid-Tertiary	calc-alkalic volcanics & plutons	Metalum. Calc-alkalic	Au +/- Cu-W veins & disseminated	Little Harquahala, Kofa
	Earliest (Mineta)	38-28	Mid-Tertiary	mostly within 'volcanic gap'	-	Uranium, clay, exotic copper	Ajo Comelia, Copper Butte (from Ray)
Laramide	Late (Wilderne ss)	55-43	Early Tertiary	2-mica, garnet-muscovite granitic stocks, sills, dikes	Peralum. Calcic, Calc-alkalic	Au dissem. & qtz veins; W veins.	Oracle (Wilderness granite), Boriana, Las Guijas, Gold Basin, Copperstone
	Middle (Morenci)	65-55	Cretaceous-Tertiary	granodiorite-quartz monzonite porphyry stocks, NE to ENE-striking dike swarms	Metaluminous Calc-alkalic	large disseminated porphyry Cu systems, local skarns & veins, fringing Zn-Pb-Ag	Ajo, Ray, Christmas, San Manuel, Mineral Park, Pima, Bagdad, Silver Bell, Globe-Miami, Morenci, Superior
	Early (Tombstone)	85-65	Late Cretaceous	qtz. monz. porph. stocks; ash flows	Metalum. Alkali-calcic	Pb-Zn-Ag veins & replacement deposits	Tombstone, Tyndall (Glove), Washington Camp, Salero
	Earliest (Hillsboro)	89-85	mid-Cretaceous	Volcanics, small stocks	Metalum. Alkalic	Cu-Au hydrothermal	Hillsboro, NM
Sevier		145-89	mid-Cretaceous			Sedimentary rocks	Bisbee Group sediments
Nevadan	Late	160-145	Late Jurassic	volcanics			
	Middle	205-160	Late & Middle Jurassic	Canelo Hills volcanics; plutonic rocks	Metalum. Alkalic	porphyry Cu-Au at Bisbee, Gleeson	Warren (Bisbee mine), Turquoise (Courtland-Gleeson)
	Early	230-205	Late Triassic	Fluid flow thru sedimentary rocks	Metalum. Alkalic	Uranium, vanadium, copper	Orphan, Grandview, Monument Valley
Alleghenian / Caledonian		220-410-380	Triassic-Devonian	None		Limestone	
Taconic		490-440	Cambrian - Ordovician	None			
Grenville		1200-900	Late Middle Proterozoic - Early Late Proterozoic	basalt flows, diabase dikes	Metalum. Alkalic	Serpentine asbestos	Sierra Ancha uranium Chrysotile (Salt R. Canyon)
"Oracle/Ruin"		1440-1335	Middle Proterozoic	K-feldspar megacrystic or porphyritic granites	Peralum. Calc-alkalic, Alkali-calcic	Pegmatites & greisens - Be, Li, Ta-Nb, U & W	White Picacho, Tungstona, Four Peaks
Mazatzal		1750-1600	Late Early Proterozoic	Basalt & rhyolite metavolc., schist	Metalum. Calcic	Cu-Zn-Ag VMS	Old Dick (Bruce)
Yavapai		1800-1775	Late Early Proterozoic	Andesite, schist, metarhyolite	Metalum. Calcic	Cu-Zn-Au VMS, Cu-Zn-Ag	Big Bug (Iron King), Verde (Jerome)
Penokean / Hudsonian		2000-1800	Middle Late Proterozoic	Schist, banded cherty iron formation	Metalum. Calcic	BIF (Banded iron formation)	Pikes Peak Iron

Precambrian Orogenies in Arizona



Orogeny	Orogenic Phase	Age (Ma)	Age (period)	Arizona Magmatism	Alkalinity	Resources	Mining districts
Grenville		1200-900	Late Middle Proterozoic – Early Late Proterozoic	basalt flows, diabase dikes	Metalum. Alkalic	Serpentine asbestos	Sierra Ancha uranium Chrysotile (Salt R. Canyon)
“Oracle/Ruin”		1440-1335	Middle Proterozoic	K-feldspar megacrystic or porphyritic granites	Peralum. Calc-alkalic, Alkali-calcic	Pegmatites & greisens – Be, Li, Ta-Nb, U & W	White Picacho, Tungstona, Four Peaks
Mazatzal		1750-1600	Late Early Proterozoic	Basalt & rhyolite metavolc., schist	Metalum. Calcic	Cu-Zn-Ag VMS	Old Dick (Bruce)
Yavapai		1800-1775	Late Early Proterozoic	Andesite, schist, metarhyolite	Metalum. Calcic	Cu-Zn-Au VMS, Cu-Zn-Ag	Big Bug (Iron King), Verde (Jerome)
Penokean/ Hudsonian		2000-1800	Middle Late Proterozoic	Schist, banded cherty iron formation	Metalum. Calcic	BIF (Banded iron formation)	Pikes Peak iron

Penokean/Hudsonian/Mohave Orogeny (2000 – 1800 Ma)

Orogeny	Orogenic Phase	Age (Ma)	Age (period)	Arizona Magmatism	Alkalinity	Resources	Mining districts
Penokean/ Hudsonian		2000-1800	Middle Late Proterozoic	Schist, banded cherty iron formation	Metalum. Calcic	BIF (Banded iron formation)	Pikes Peak iron

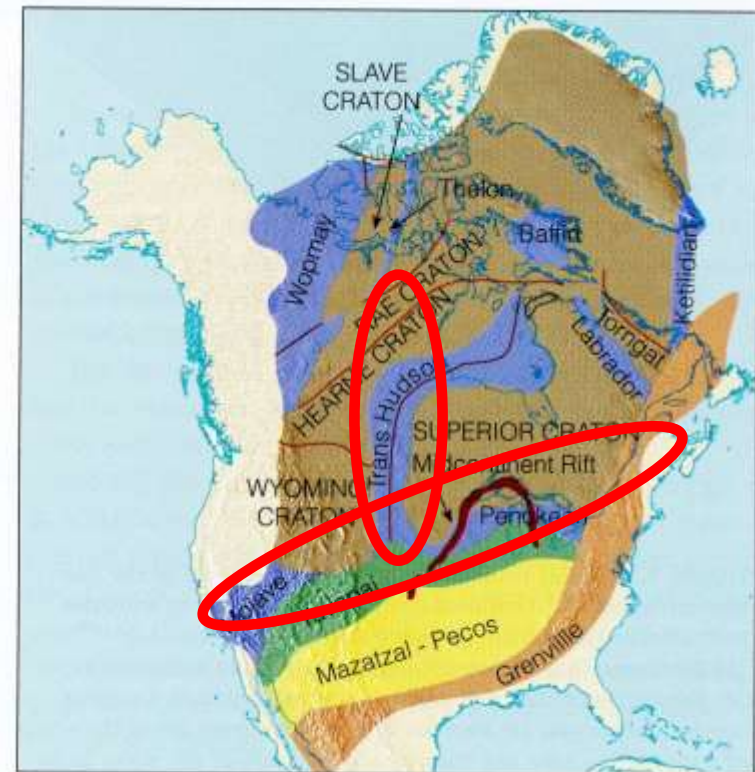
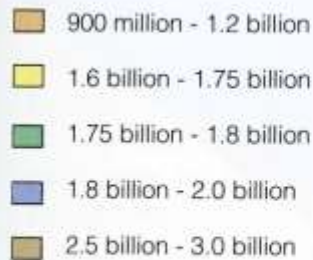


FIGURE 9.2 Proterozoic evolution of the Laurentian craton. (a) During the Early Proterozoic, Archean cratons were sutured along deformation belts called *orogens*. (b) Laurentia grew along its southern margin by accretion of the Central Plains, Yavapai, and Mazatzal orogens. (c) A final episode of Proterozoic accretion occurred during the Grenville orogeny.

(c)

Penokean – Pikes Peak BIF

Banded Iron Formation

Hieroglyphic Mountains (Pikes Peak) Hematite-Magnetite
Taconite, north-central Maricopa County - Iron Age, Pig Iron, and Bessemer



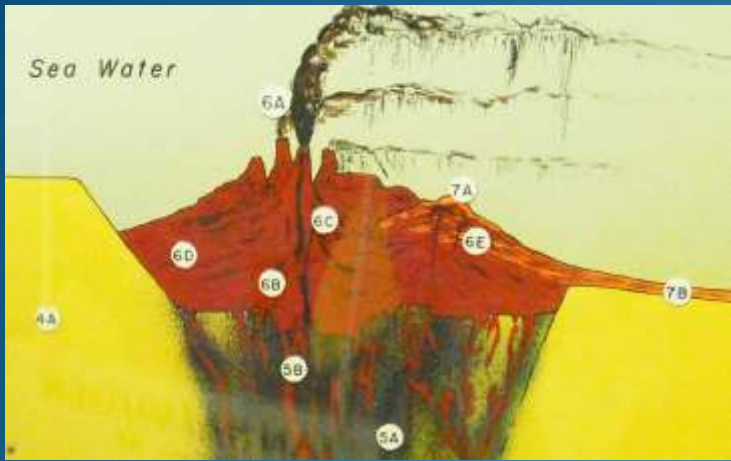
FIGURE 22. - Taconite-Like Hematite-Magnetite Iron Formation, Hieroglyphic Mountains, T 6 N, Rs 1 and 2 W, Maricopa County, Ariz. Note banded, laminated structure.



BIF (Jerome Historical museum) Paul Lindberg sample

Yavapai Jerome VMS (1800 – 1775 Ma)

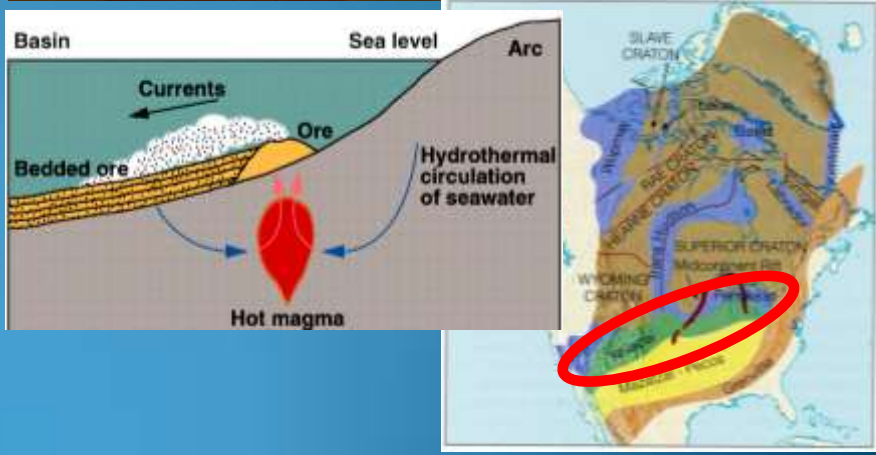
Orogeny	Orogenic Phase	Age (Ma)	Age (period)	Arizona Magmatism	Alkalinity	Resources	Mining districts
Yavapai		1800-1775	Late Early Proterozoic	Andesite, schist, metarhyolite	Metalum. Calcic	Cu-Zn-Au VMS, Cu-Zn-Ag	Big Bug (Iron King), Verde (Jerome)



3D model of Verde deposit by Paul Lindberg, Jerome Historical museum



Jerome Volcanogenic Massive Sulfide



Jerome (Verde m.d.) (1800 – 1775 Ma)

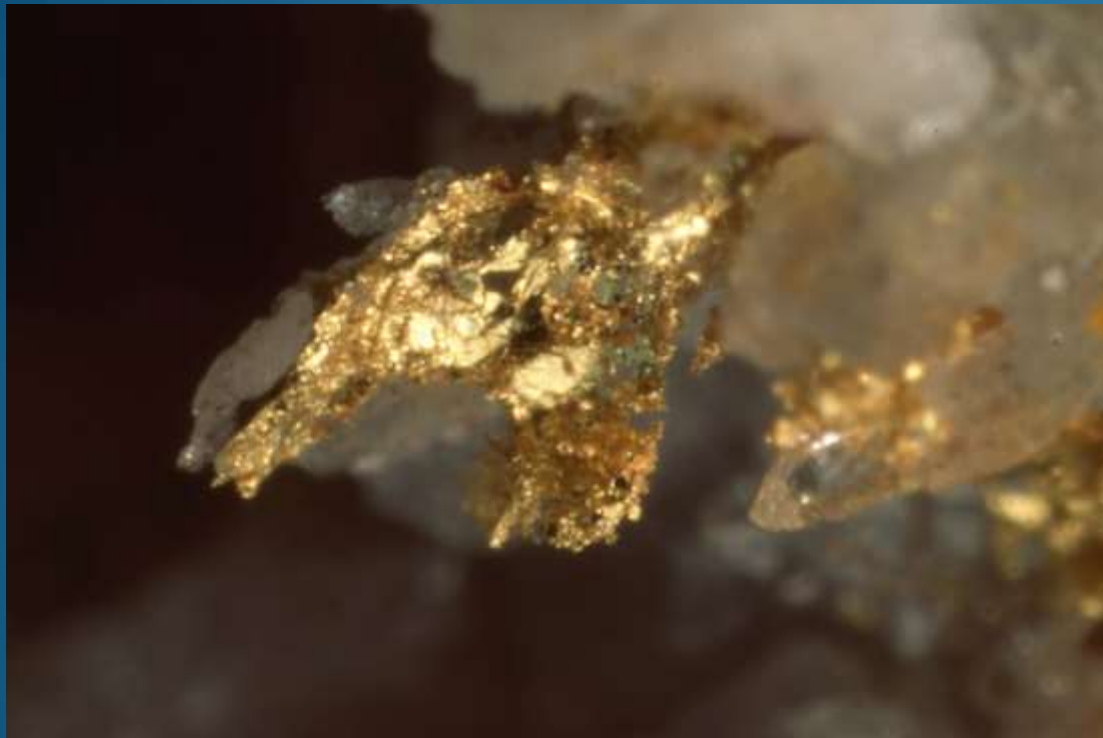
Orogeny	Orogenic Phase	Age (Ma)	Age (period)	Arizona Magmatism	Alkalinity	Resources	Mining districts
Yavapai		1800-1775	Late Early Proterozoic	Andesite, schist, metarhyolite	Metalum. Calcic	Cu-Zn-Au VMS, Cu-Zn-Ag	Big Bug (Iron King), Verde (Jerome)



Volcanogenic Massive Sulfide

Yavapai - Big Bug – Iron King VMS

Orogeny	Orogenic Phase	Age (Ma)	Age (period)	Arizona Magmatism	Alkalinity	Resources	Mining districts
Yavapai		1800-1775	Late Early Proterozoic	Andesite, schist, metarhyolite	Metalum. Calcic	Cu-Zn-Au VMS, Cu-Zn-Ag	Big Bug (Iron King), Verde (Jerome)



Gold from Big Bug mine
Sugar White photo, Ed Huskinson sample



Mazatzal Orogeny (1750-1600 Ma)

Orogeny	Orogenic Phase	Age (Ma)	Age (period)	Arizona Magmatism	Alkalinity	Resources	Mining districts
Mazatzal		1750-1600	Late Early Proterozoic	Basalt & rhyolite metavolc., schist	Metalum. Calcic	Cu-Zn-Ag VMS	Old Dick (Bruce)

The Old Dick (Bruce) mine is a

- former underground Zn-Cu-Ag-Au-Pb-As-Co-Cd mine
- located 2¾ miles SSW of Bagdad.
- volcanogenic massive sulfide deposit
- stratiform ore bodies hosted in the Brindle Formation and the Dick Rhyolite
- ore lenses consist of resinous yellowish-brown and black sphalerite
- pyrite concentrated in irregularly spaced, narrow bands
- chalcopyrite in minute stringers and wide
- galena in local pods
- disseminated tiny euhedral arsenopyrite crystals
- sphalerite veinlets
- some gold and silver

Information source: MinDat.org



Hillside mine, Eureka dist., Yav. Co.; source: Baird, mindat.org

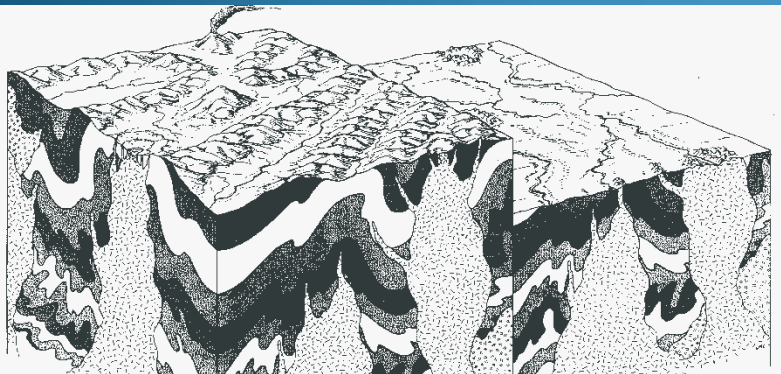


Oracle “anorogenic” Orogeny (1440-1335 Ma)

Orogeny	Orogenic Phase	Age (Ma)	Age (period)	Arizona Magmatism	Alkalinity	Resources	Mining districts
“Oracle/Ruin”		1440-1335	Middle Proterozoic	K-feldspar megacrystic or porphyritic granites	Peralum. Calc-alkalic, Alkali-calcic	Pegmatites & greisens – Be, Li, Ta-Nb, U & W	White Picacho, Tungstona, Four Peaks

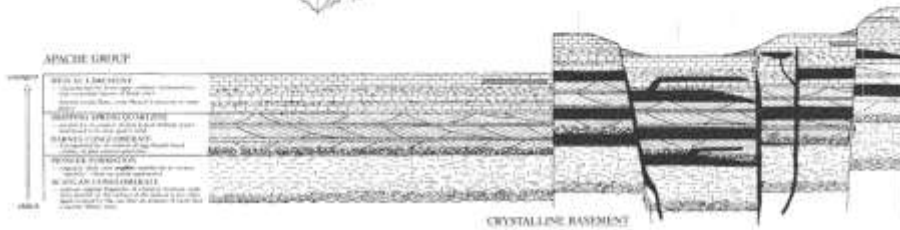
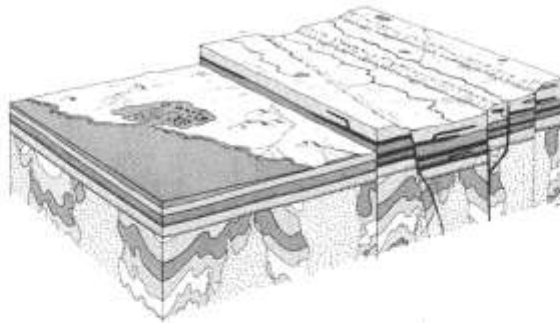


Oracle Granite, Santa Catalina Mts.



Grenville Orogeny (1200-900 Ma)

Orogeny	Orogenic Phase	Age (Ma)	Age (period)	Arizona Magmatism	Alkalinity	Resources	Mining districts
Grenville		1200-900	Late Middle Proterozoic – Early Late Proterozoic	basalt flows, diabase dikes	Metalum. Alkalic	Serpentine asbestos	Sierra Ancha uranium Chrysotile (Salt R. Canyon)

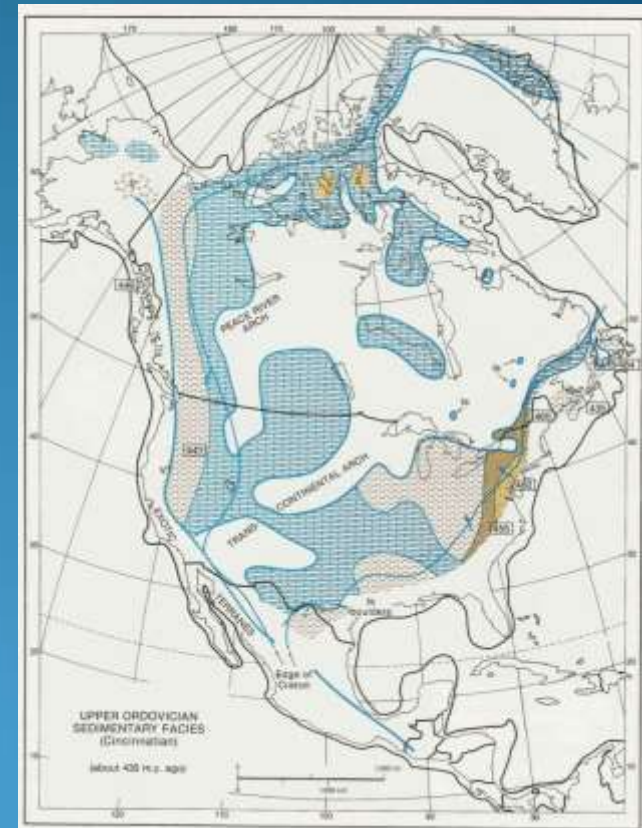
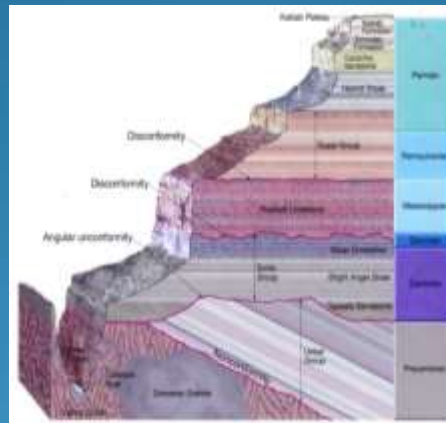
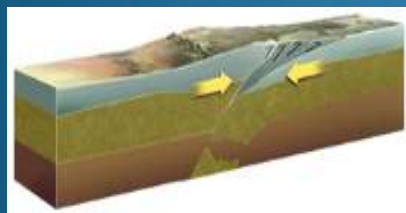
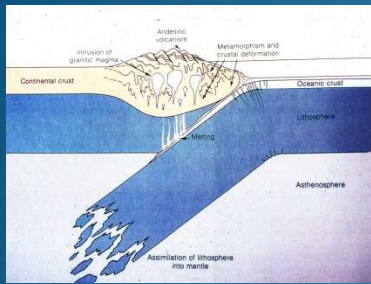


Chrysotile
asbestos, Salt
River Canyon



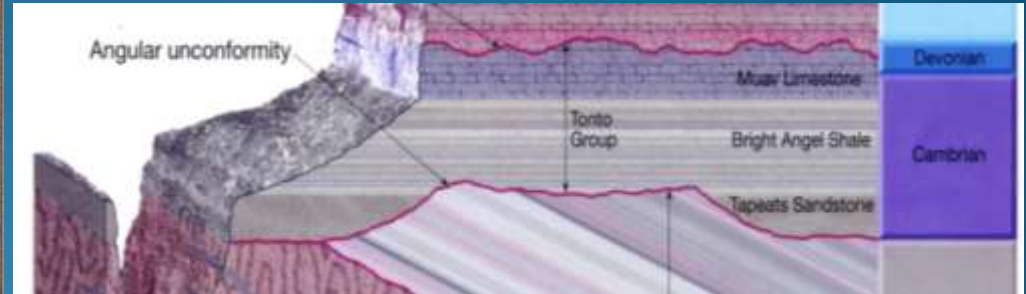
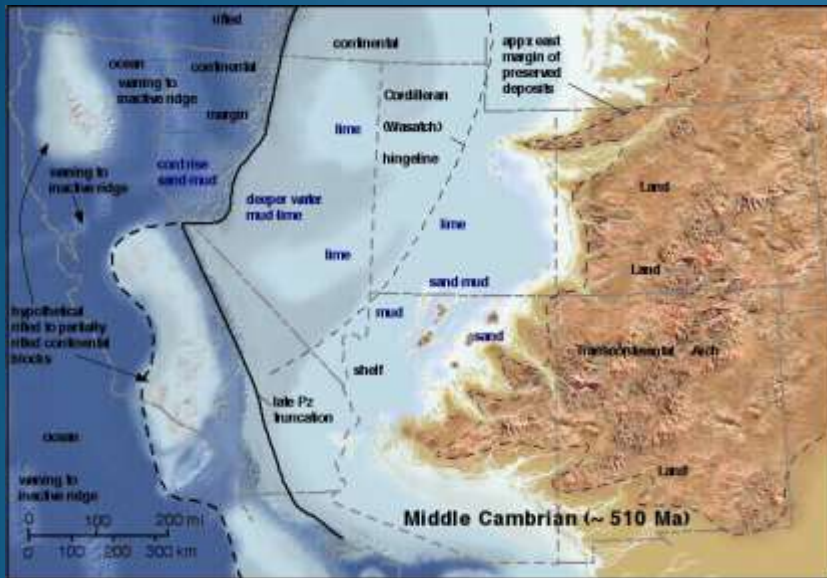
Paleozoic Orogenies in eastern U.S.

Orogeny	Orogenic Phase	Age (Ma)	Age (period)	Arizona Magmatism	Alkalinity	Resources	Mining districts
				ROCKS		Copper	
Alleghenian (Ouachita)		325-220	Miss. – Triassic	None	-	U in sed. rocks	Payson uranium
Acadian/ Caledonian		410-380	Devonian	None	-	Limestone	
Taconic.		490-445	Cambrian – Ord.	None	-		



Taconic sedimentation in Arizona

Orogeny	Orogenic Phase	Age (Ma)	Age (period)	Arizona Magmatism	Alkalinity	Resources	Mining districts
Taconic.		490-445	Cambrian – Ord.	None	-		



Tonto Group, Grand Canyon (Tapeats Ss. Ledge, overlain by Bright Angel Shale slope, and Muav Ls. ledge)



Bolsa Quartzite on skyline, Rosemont Copper, Santa Rita Mts.

Acadian/Caledonian sedimentation in Arizona

Orogeny	Orogenic Phase	Age (Ma)	Age (period)	Arizona Magmatism	Alkalinity	Resources	Mining districts
Acadian/ Caledonian		410-380	Devonian	None	-	Limestone	

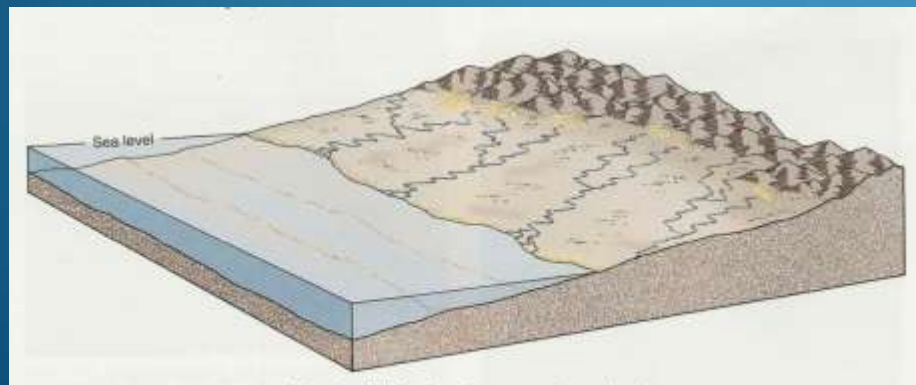


FIGURE 9-24 A panoramic view of the Catskill elastic wedge as seen from a location above south-central Pennsylvania. Shoreline trends for about 300 kilometers in a northeastern direction. (Modified from Woodrow, D. L. 1985. *Geol. Soc. Am. Special Paper* 201:51-63.)

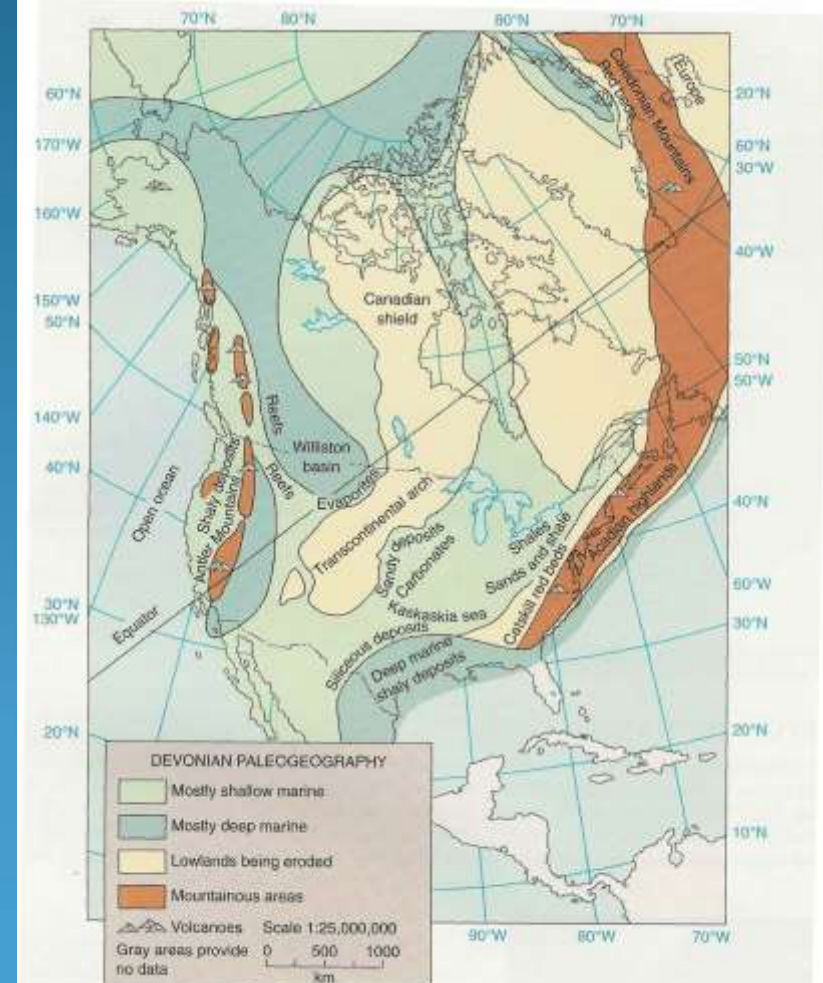
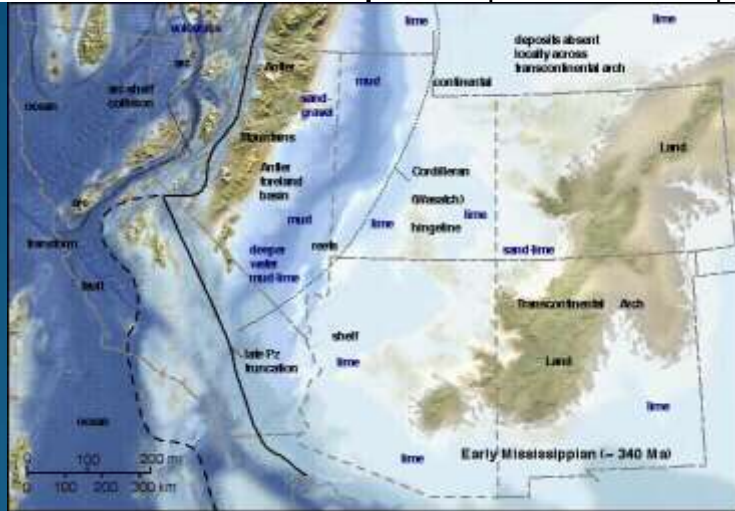


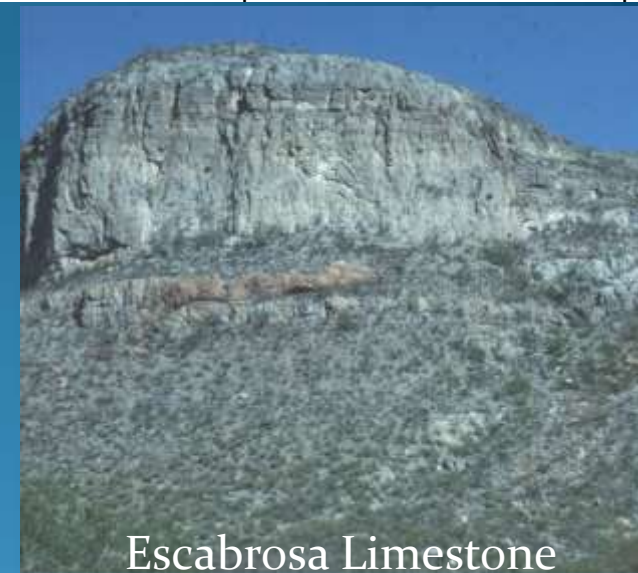
FIGURE 9-4 Paleogeography of North America during the Devonian Period.

Lull - Mississippian Limestones in Arizona

Orogeny	Orogenic Phase	Age (Ma)	Age (period)	Arizona Magmatism	Alkalinity	Resources	Mining districts
Alleghenian (Ouachita)		325-220	Miss. – Triassic	None	-	U in sed. rocks	Payson uranium
Acadian/ Caledonian		410-380	Devonian	None	-	Limestone	



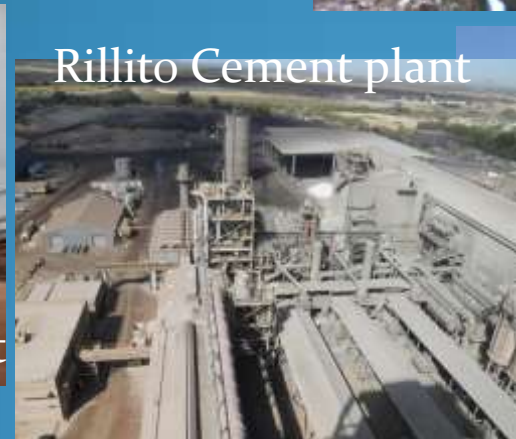
Redwall Limestone



Escabrosa Limestone



Clarkdale Cement plant



Rillito Cement plant



Sahuarita Marble

Alleghenian sedimentation in Arizona

Orogeny	Orogenic Phase	Age (Ma)	Age (period)	Arizona Magmatism	Alkalinity	Resources	Mining districts
				rocks		Copper	
Alleghenian (Ouachita)		325-220	Miss. – Triassic	None	-	U in sed. rocks	Payson uranium



Sedona – Supai Group



A.



Government Butte, S. of Tombstone



Jan on Permian Colina Ls. 1967

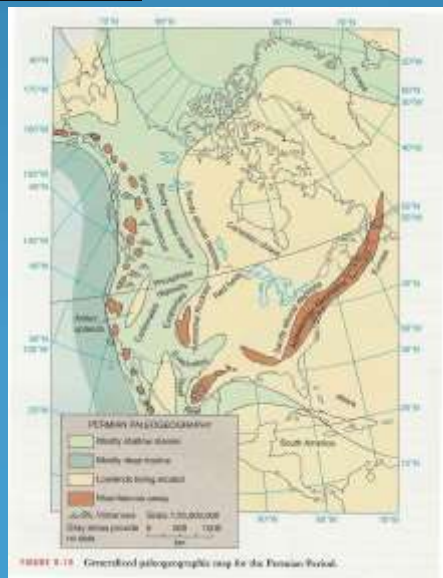


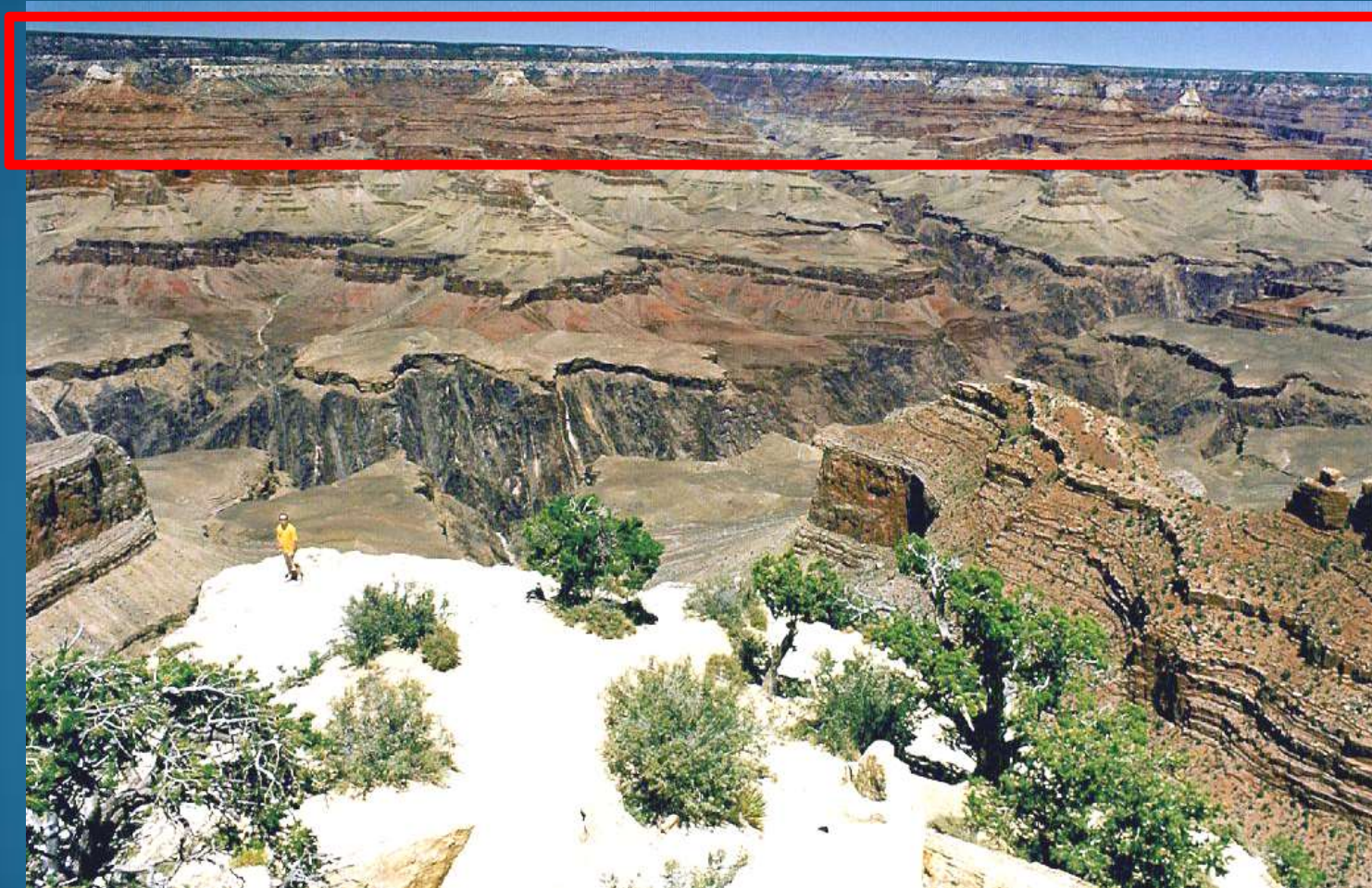
FIGURE 1-15 Geotectonic paleogeographic map for the Permian Period.



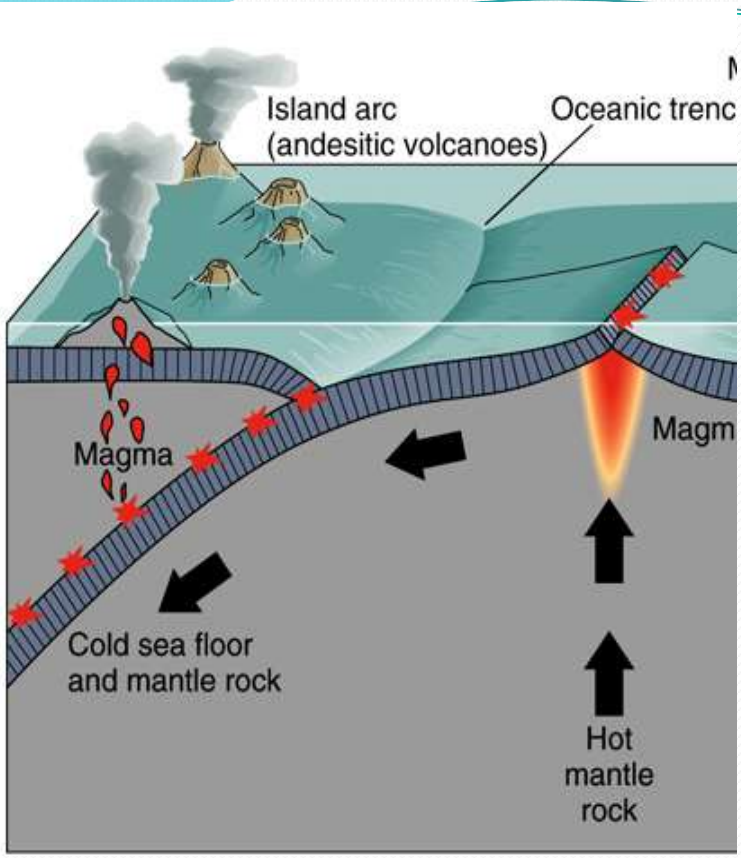
Goosenecks of the San Juan R., Hermosa Fm.

Alleghenian sedimentation in Arizona

Orogeny	Orogenic Phase	Age (Ma)	Age (period)	Arizona Magmatism	Alkalinity	Resources	Mining districts
				rocks		copper	
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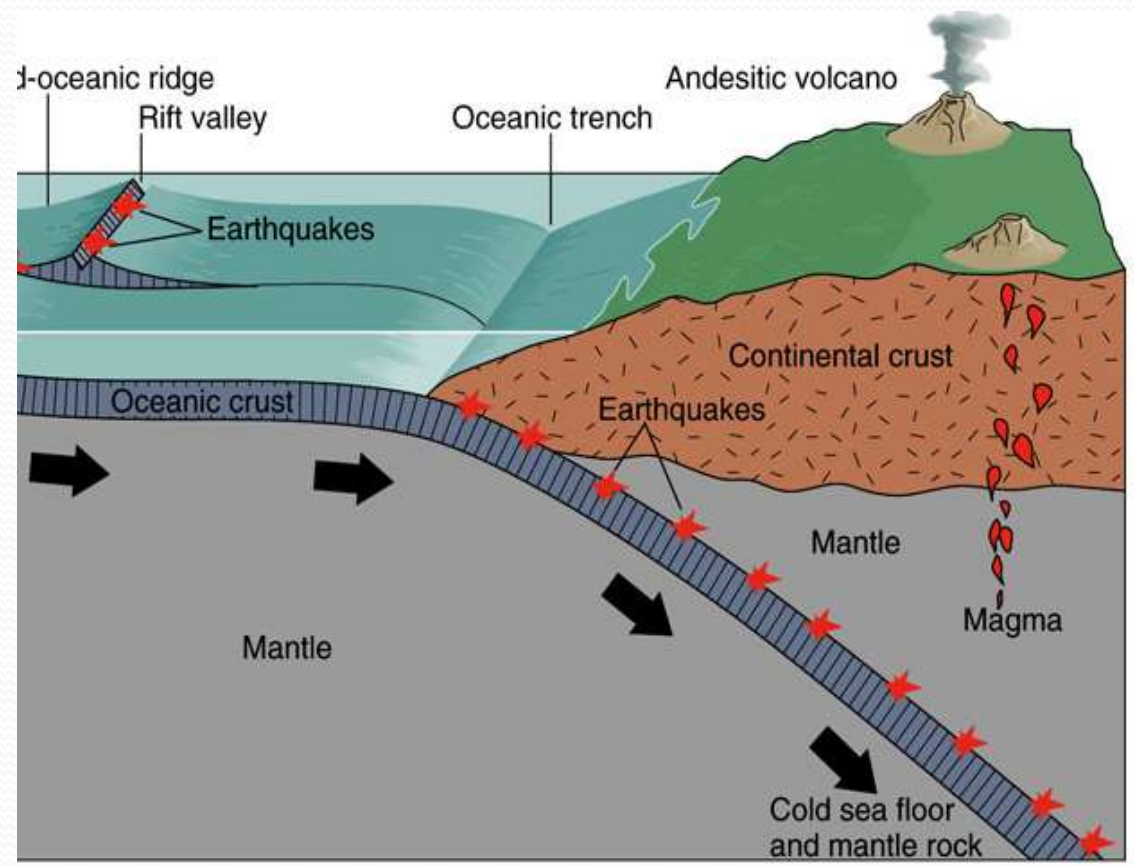


Arizona's position w.r.t. plate tectonics in Paleozoic vs. Mesozoic



Paleozoic – Arizona was on trailing edge of N. American continent = calm seaways

Mesozoic – Arizona was on leading edge of N. American continent = mountain building, volcanoes, earthquakes, igneous intrusions

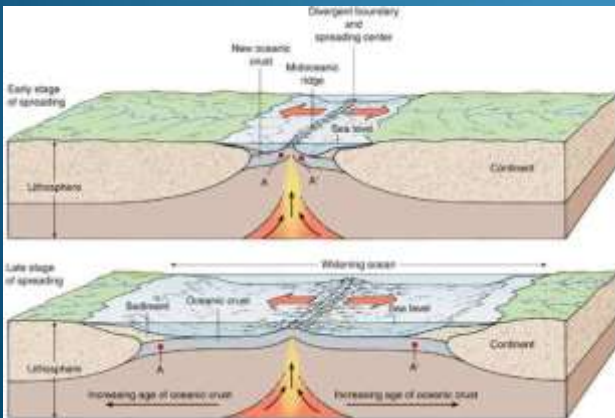
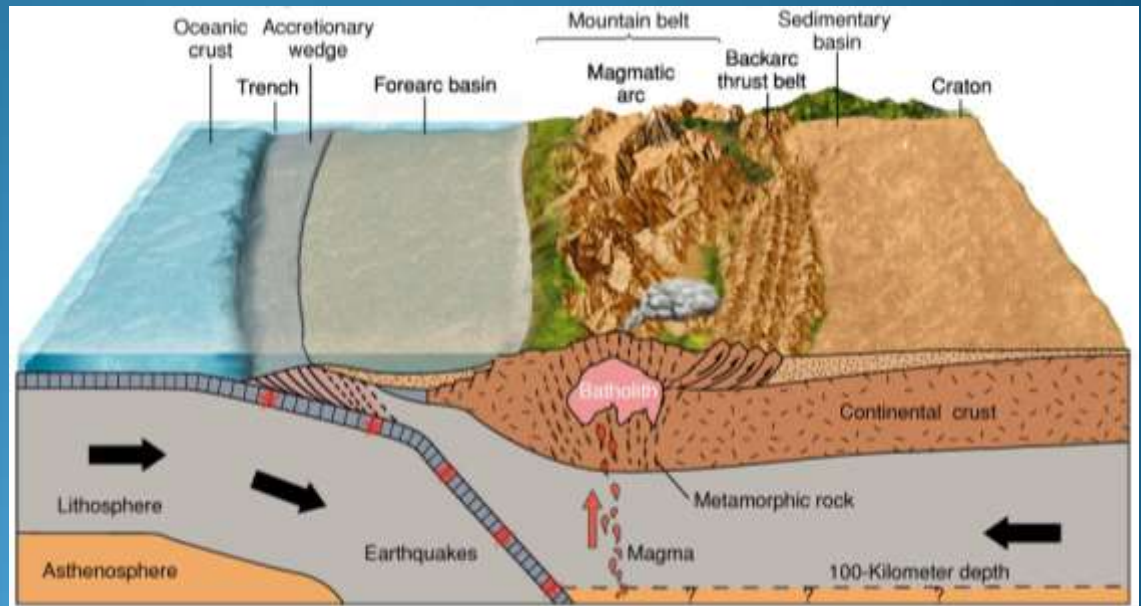


Mesozoic – Cenozoic Orogenies

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	Early	230-205	Late Triassic	Fluid flow thru sedimentary rocks	Metalum. Alkalic	Uranium, vanadium, copper	Orphan, Grandview, Monument Valley

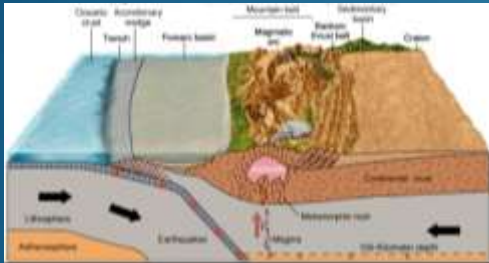
Nevadan Orogeny (230-145 Ma)

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Early Nevadan Orogeny (230-205 Ma)

Orogeny	Orogenic Phase	Age (Ma)	Age (period)	Arizona Magmatism	Alkalinity	Resources	Mining districts
Nevadan	Late	160-145	Late Jurassic	volcanics			
	Middle	205-160	Late & Middle Jurassic	Canelo Hills volcanics; plutonic rocks	Metalum. Alkalic	porphyry Cu-Au at Bisbee, Gleeson	Warren (Bisbee mine), Turquoise (Courtland-Gleeson)
	Early	230-205	Late Triassic	Fluid flow thru sedimentary rocks	Metalum. Alkalic	Uranium, vanadium, copper	Orphan, Grandview, Monument Valley

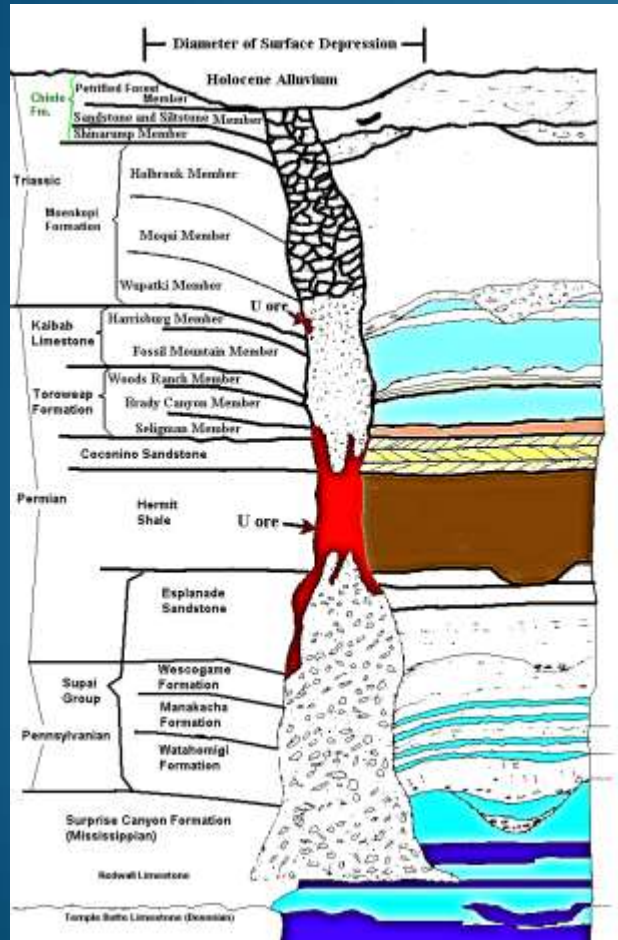


Petrified Forest Member, Chinle Fm



Early Jurassic Orogeny (230-200 Ma)

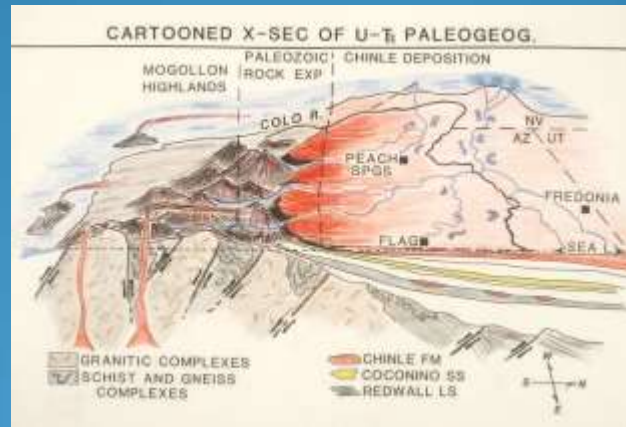
Orogeny	Orogenic Phase	Age (Ma)	Age (period)	Arizona Magmatism	Alkalinity	Resources	Mining districts
	Early	230-205	Late Triassic	Fluid flow thru sedimentary rocks	Metalum. Alkalic	Uranium, vanadium, copper	Orphan, Grandview, Monument Valley



Source: Wenrich



Ridenour mine; tyuyamunite, Wenrich



Source: Wenrich



CHINITZITE OR ANHYDRITE
from Ridenour, Tropic Falls, High Uintas National Monument, Grandview Mining District, Coconino Co., AZ
Source: Jan Rasmussen

Jurassic arc magmatism

Orogeny	Orogenic Phase	Age (Ma)	Age (period)	Arizona Magmatism	Alkalinity	Resources	Mining districts
Nevadan	Middle	205-160	Late & Middle Jurassic	Canelo Hills volcanics; plutonic rocks	Metalum. Alkalic	porphyry Cu-Au at Bisbee, Gleeson	Warren (Bisbee mine), Turquoise (Courtland-Gleeson)

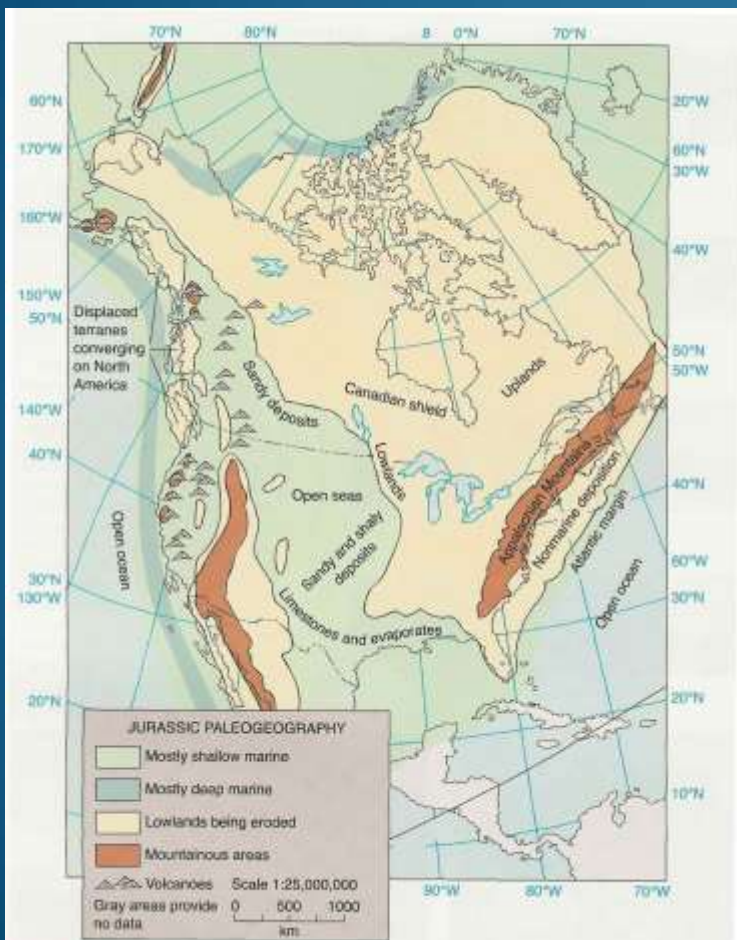


FIGURE 11-7 Generalized paleogeographic map for the Jurassic of North America.



Santa Rita Mts., Mt. Wrightson



Paleogeographic maps from Blakey & Ranney



Middle Nevadan - Warren m.d. (Bisbee)

Orogeny	Orogenic Phase	Age (Ma)	Age (period)	Arizona Magmatism	Alkalinity	Resources	Mining districts
Nevadan	Middle	205-160	Late & Middle Jurassic	Canelo Hills volcanics; plutonic rocks	Metalum. Alkalic	porphyry Cu-Au at Bisbee, Gleeson	Warren (Bisbee mine), Turquoise (Courtland-Gleeson)



chalcopyrite
bornite
sphalerite
Pyrite - gangue

Warren district (Bisbee) azurite

Orogeny	Orogenic Phase	Age (Ma)	Age (period)	Arizona Magmatism	Alkalinity	Resources	Mining districts
Nevadan	Middle	205-160	Late & Middle Jurassic	Canelo Hills volcanics; plutonic rocks	Metalum. Alkalic	porphyry Cu-Au at Bisbee, Gleeson	Warren (Bisbee mine), Turquoise (Courtland-Gleeson)



Warren district (Bisbee) secondary

Orogeny	Orogenic Phase	Age (Ma)	Age (period)	Arizona Magmatism	Alkalinity	Resources	Mining districts
Nevadan	Middle	205-160	Late & Middle Jurassic	Canelo Hills volcanics; plutonic rocks	Metalum. Alkalic	porphyry Cu-Au at Bisbee, Gleeson	Warren (Bisbee mine), Turquoise (Courtland-Gleeson)



MALACHITE
Copper Carbonate Hydroxide
 $Cu_2CO_3(OH)_2$
Bisbee, Cochise Co., AZ
Donor: Dennis P. Hill MM-4455

CUPRITE variety Chalcotrichite
Copper Oxide
 Cu_2O
Bisbee, Cochise Co., AZ
Donor: Virginia L. Krotz MM-5013

TURQUOISE
Copper Aluminum Phosphate Hydroxide Hydrate
 $Cu_2Al_2(PO_4)_2(OH)_2 \cdot 4H_2O$
Bisbee, Cochise Co., AZ
Donor: Phelps Dodge Corporation MM-4202

BOURNONITE
Lead Copper Antimony Sulfide
 $PbCuSbS_3$
Bisbee, Cochise Co., AZ
Donor: Virginia L. Krotz Collection MM-6457

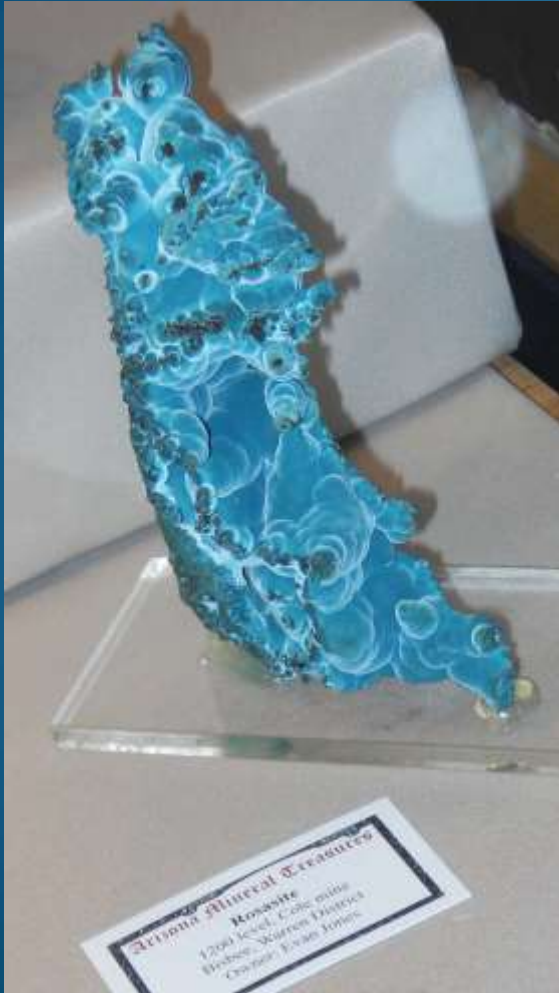
Warren district (Bisbee) secondary

Orogeny	Orogenic Phase	Age (Ma)	Age (period)	Arizona Magmatism	Alkalinity	Resources	Mining districts
Nevadan	Middle	205-160	Late & Middle Jurassic	Canelo Hills volcanics; plutonic rocks	Metalum. Alkalic	porphyry Cu-Au at Bisbee, Gleeson	Warren (Bisbee mine), Turquoise (Courtland-Gleeson)



Warren district (Bisbee) secondary

Orogeny	Orogenic Phase	Age (Ma)	Age (period)	Arizona Magmatism	Alkalinity	Resources	Mining districts
Nevadan	Middle	205-160	Late & Middle Jurassic	Canelo Hills volcanics; plutonic rocks	Metalum. Alkalic	porphyry Cu-Au at Bisbee, Gleeson	Warren (Bisbee mine), Turquoise (Courtland-Gleeson)



Turquoise district – Courtland-Gleeson

Orogeny	Orogenic Phase	Age (Ma)	Age (period)	Arizona Magmatism	Alkalinity	Resources	Mining districts
Nevadan	Middle	205-160	Late & Middle Jurassic	Canelo Hills volcanics; plutonic rocks	Metalum. Alkalic	porphyry Cu-Au at Bisbee, Gleeson	Warren (Bisbee mine), Turquoise (Courtland-Gleeson)

Early and Middle Jurassic age dates



Silver Bill mine, wulfenite

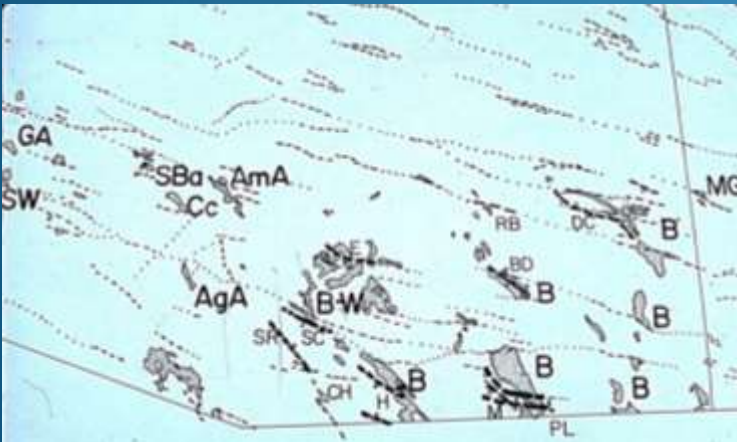
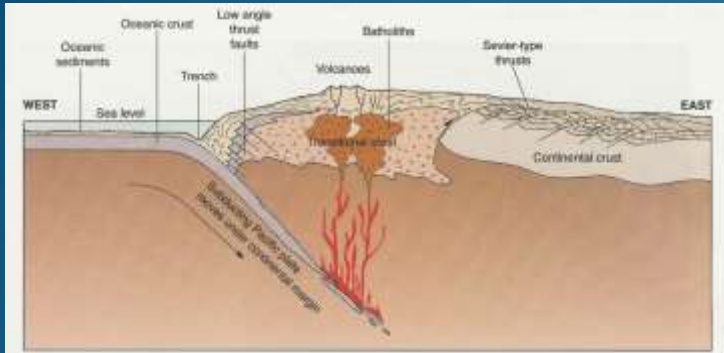


Defiance mine, wulfenite, Donor: Les Presmyk

Courtland area = possible Quartz Alkalic; Gleeson Ridge = possible Alkali-calcic

Sevier Orogeny (145-89 Ma)

Orogeny	Orogenic Phase	Age (Ma)	Age (period)	Arizona Magmatism	Alkalinity	Resources	Mining districts
Sevier		145-89	mid-Cretaceous			Sedimentary rocks	Bisbee Group sediments



Mural Ls. (Bisbee Group) E. of Bisbee

Laramide Orogeny (89-43 Ma)

Orogeny	Orogenic Phase	Age (Ma)	Age (period)	Arizona Magmatism	Alkalinity	Resources	Mining districts
Laramide	Late (Wilderness)	55-43	Early Tertiary	2-mica, garnet-muscovite granitic stocks, sills, dikes	Peralum. Calcic, Calc-alkalic	Au dissem. & qtz veins; W veins,	Oracle (Wilderness granite), Boriانا, Las Guijas, Gold Basin, Copperstone
	Middle (Morenci)	65-55	Cretaceous-Tertiary	granodiorite - quartz monzonite porphyry stocks, NE to ENE-striking dike swarms	Metaluminous Calc-alkalic	large disseminated porphyry Cu systems, local skarns & veins, fringing Zn-Pb-Ag	Ajo, Ray, Christmas, San Manuel, Mineral Park, Pima, Bagdad, Silver Bell, Globe-Miami, Morenci, Superior
	Early (Tombstone)	85-65	Late Cretaceous	qtz. monz. porph. stocks; ash flows	Metalum. Alkali-calcic	Pb-Zn-Ag veins & replacement deposits	Tombstone, Tyndall (Glove), Washington Camp, Salero
	Earliest (Hillsboro)	89-85	mid-Cretaceous	Volcanics, small stocks	Metalum. Alkalic	Cu-Au hydrothermal	Hillsboro, NM



Ray



Mission

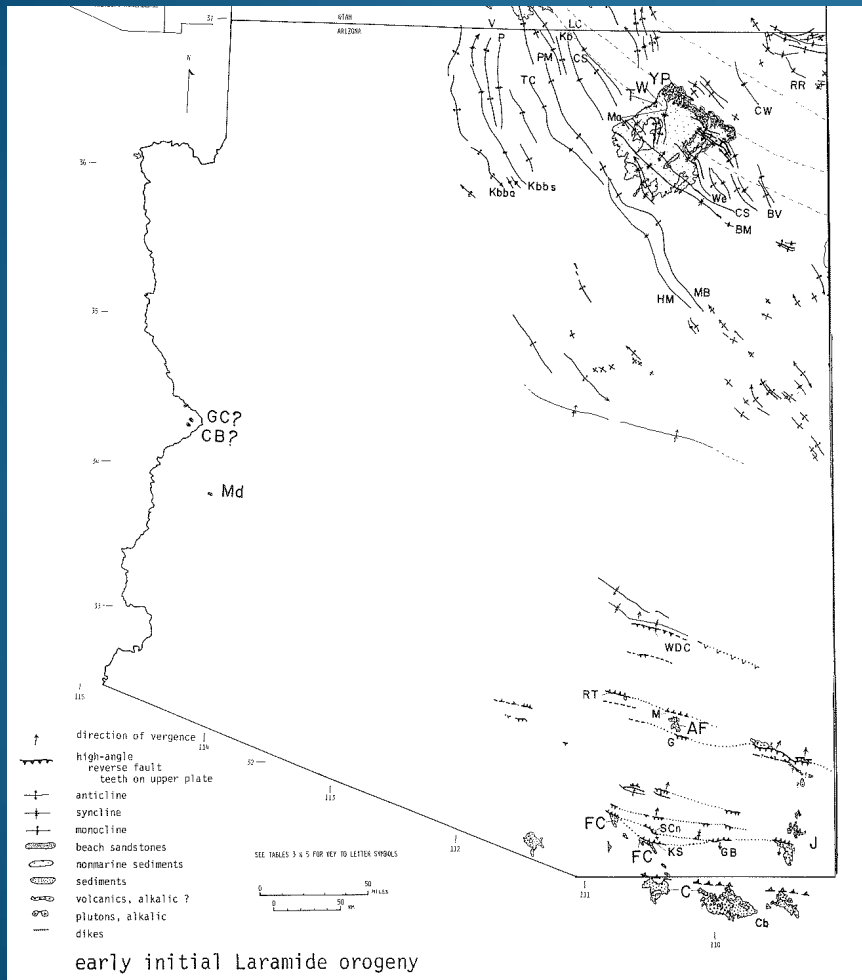


Silver Bell

Photos courtesy of ASARCO (Grupo)

Earliest Laramide - Hillsboro (89-85 Ma)

Orogeny	Orogenic Phase	Age (Ma)	Age (period)	Arizona Magmatism	Alkalinity	Resources	Mining districts
	Earliest (Hillsboro)	89-85	mid-Cretaceous	Volcanics, small stocks	Metalum. Alkalic	Cu-Au hydrothermal	Hillsboro, NM



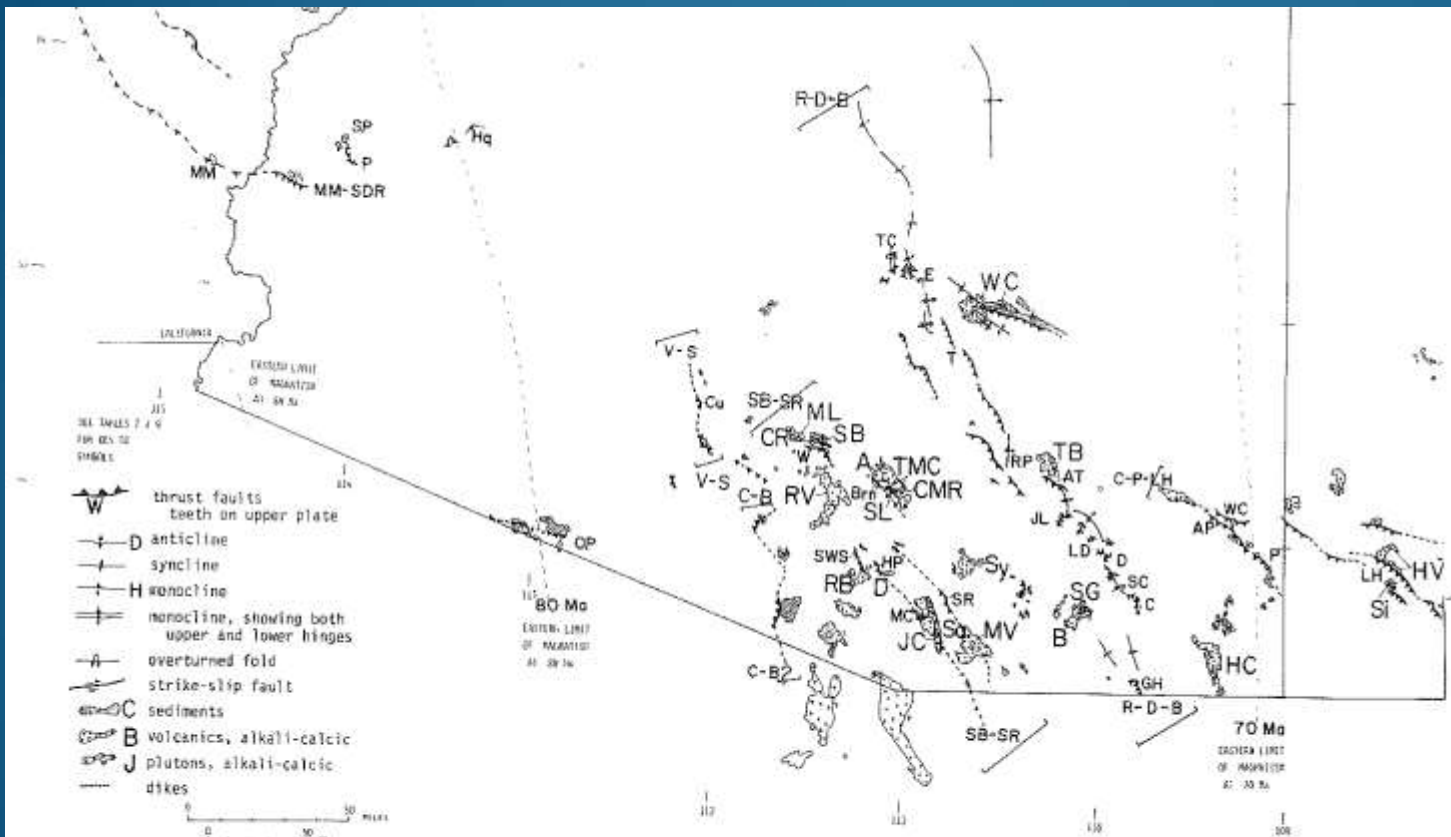
N Arizona – coal in Wepo Fm. at Black Mesa



Photo from Peabody Coal (Freeport-McMoran)

Early Laramide (Tombstone) (85-65 Ma)

Orogeny	Orogenic Phase	Age (Ma)	Age (period)	Arizona Magmatism	Alkalinity	Resources	Mining districts
	Early (Tombstone)	85-65	Late Cretaceous	qtz. monz. porph. stocks; ash flows	Metalum. Alkali-calcic	Pb-Zn-Ag veins & replacement deposits	Tombstone, Tyndall (Glove), Washington Camp, Salero



late initial Laramide orogeny

Figure 4. Map of Denver and Tombstone Assemblages of the late initial Laramide orogeny in Arizona and vicinity.



Early Laramide (Tombstone) (85-65 Ma)

Orogeny	Orogenic Phase	Age (Ma)	Age (period)	Arizona Magmatism	Alkalinity	Resources	Mining districts
	Early (Tombstone)	85-65	Late Cretaceous	qtz. monz. porph. stocks; ash flows	Metalum. Alkali-calcic	Pb-Zn-Ag veins & replacement deposits	Tombstone, Tyndall (Glove), Washington Camp, Salero



Tombstone Hills – Uncle Sam Tuff



Tucson Mts. - Cat Mountain Rhyolite – 74 Ma ignimbrite (rhyolite ash flows)



Mt. Pinatubo, Philippines 1991

Tombstone silver mines

Orogeny	Orogenic Phase	Age (Ma)	Age (period)	Arizona Magmatism	Alkalinity	Resources	Mining districts
	Early (Tombstone)	85-65	Late Cretaceous	qtz. monz. porph. stocks; ash flows	Metalum. Alkali-calcic	Pb-Zn-Ag veins & replacement deposits	Tombstone, Tyndall (Glove), Washington Camp, Salero



Emmonsite,
Megaw
specimen,
Sugar White
photo



Chlorargyrite – John Betts
photo & specimen
MinDat.org



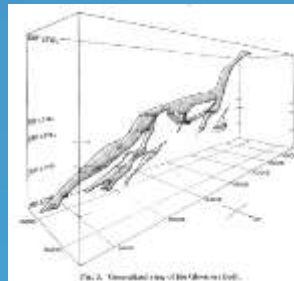
Dugganite – Empire mine.
Peter Megaw specimen and
Sugar White photograph



Megaw specimen,
Sugar White photo

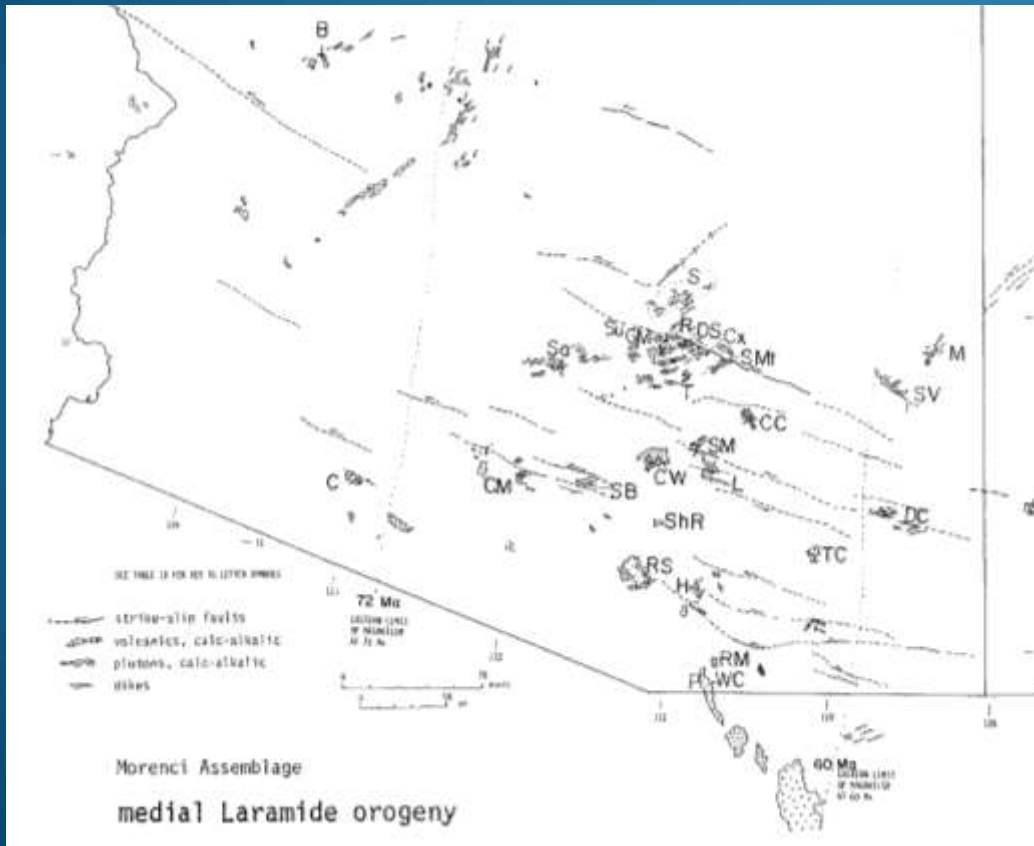
Glove mine, Santa Rita Mts.

- Argentiferous galena, sphalerite, small amounts of pyrite, chalcopyrite & quartz
- Deposited in permeable zones at the intersection of a bedding plane fault and favorable beds in Permian Naco Limestone
- Extensive solution of the limestone and deep oxidation concentrated cerussite, anglesite, wulfenite, & smithsonite in the leached caverns as sand carbonate ore



Middle Laramide - Morenci (65-55 Ma)

Orogeny	Orogenic Phase	Age (Ma)	Age (period)	Arizona Magmatism	Alkalinity	Resources	Mining districts
Laramide	Middle (Morenci)	65-55	Cretaceous-Tertiary	granodiorite - quartz monzonite porphyry stocks, NE to ENE-striking dike swarms	Metaluminous Calc-alkalic	large disseminated porphyry Cu systems, local skarns & veins, fringing Zn-Pb-Ag	Ajo, Ray, Christmas, San Manuel, Mineral Park, Pima, Bagdad, Silver Bell, Globe-Miami, Morenci, Superior



Laramide porphyry copper (65-55 Ma)

Orogeny	Orogenic Phase	Age (Ma)	Age (period)	Arizona Magmatism	Alkalinity	Resources	Mining districts
Laramide	Middle (Morenci)	65-55	Cretaceous-Tertiary	granodiorite - quartz monzonite porphyry stocks, NE to ENE-striking dike swarms	Metaluminous Calc-alkalic	large disseminated porphyry Cu systems, local skarns & veins, fringing Zn-Pb-Ag	Ajo, Ray, Christmas, San Manuel, Mineral Park, Pima, Bagdad, Silver Bell, Globe-Miami, Morenci, Superior



Ray mine



Ray shovel, haul truck
Dave Briggs photos



Middle Laramide - Morenci (65-55 Ma)

Orogeny	Orogenic Phase	Age (Ma)	Age (period)	Arizona Magmatism	Alkalinity	Resources	Mining districts
Laramide	Middle (Morenci)	65-55	Cretaceous-Tertiary	granodiorite - quartz monzonite porphyry stocks, NE to ENE-striking dike swarms	Metaluminous Calc-alkalic	large disseminated porphyry Cu systems, local skarns & veins, fringing Zn-Pb-Ag	Ajo, Ray, Christmas, San Manuel, Mineral Park, Pima, Bagdad, Silver Bell, Globe-Miami, Morenci, Superior



Ajo



San Manuel



Miami-Globe



Bagdad



Ray



Morenci

Pima district (Mission m.) porphyry copper deposits



Bornite – peacock
copper – copper iron
sulfide



Chalcopyrite –
copper fools gold
Copper-iron-sulfide

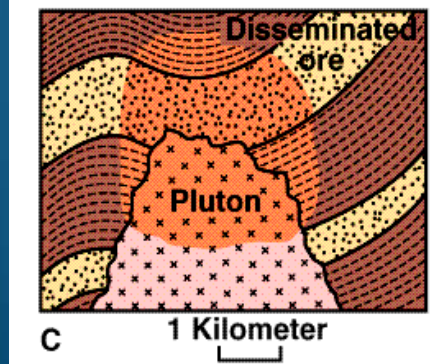
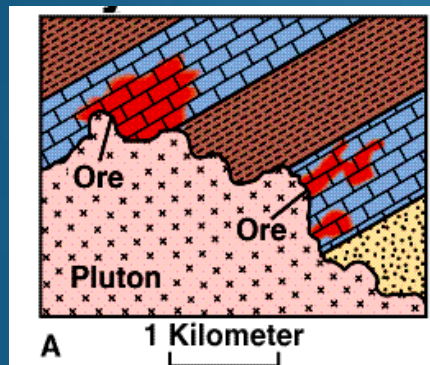


Superior – Magma mine

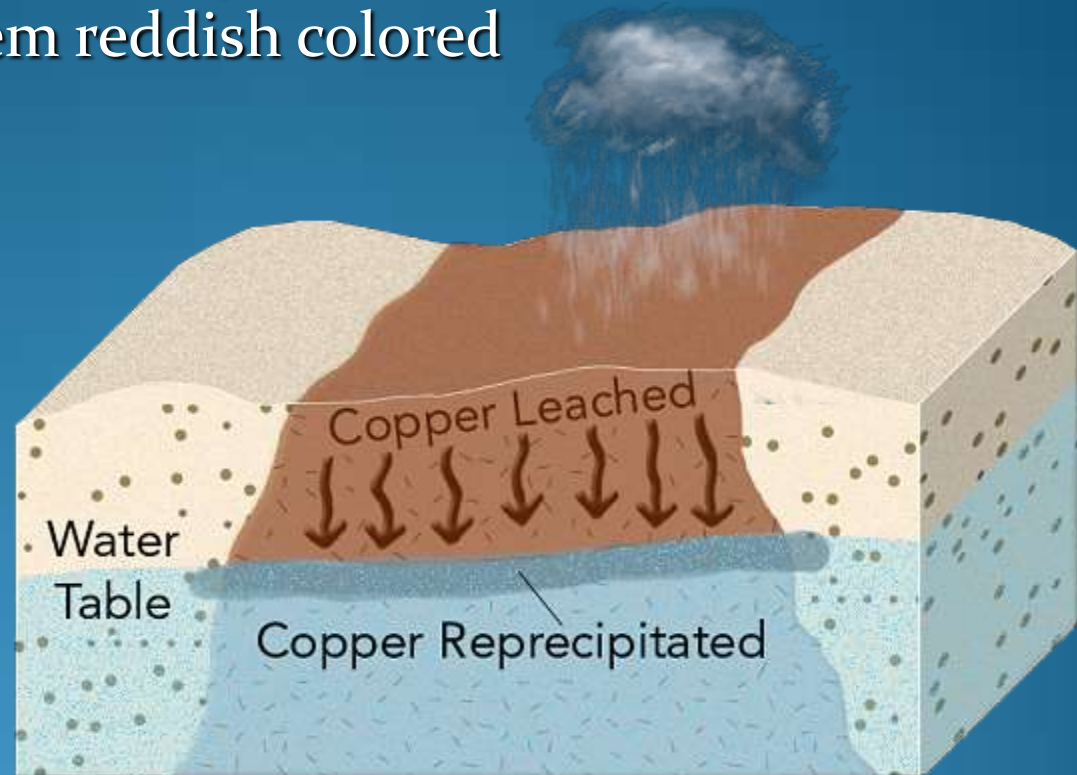


Porphyry Copper mineralization

Primary - sulfides

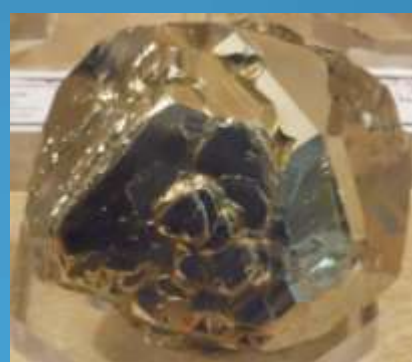


Weathering leaches copper from top, leaving them reddish colored



Copper is precipitated at the water table, enriching deposit with chalcocite, copper, azurite, malachite, chrysocolla

San Manuel mine 1998



Outer Pb-Zn zones of Porphyry Copper deposits

79 mine



Outer Pb-Zn zones of Porphyry Copper deposits

79 mine



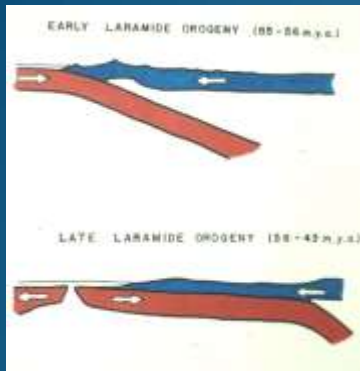
Outer Pb-Zn zones of Porphyry Copper deposits

- Christmas mine

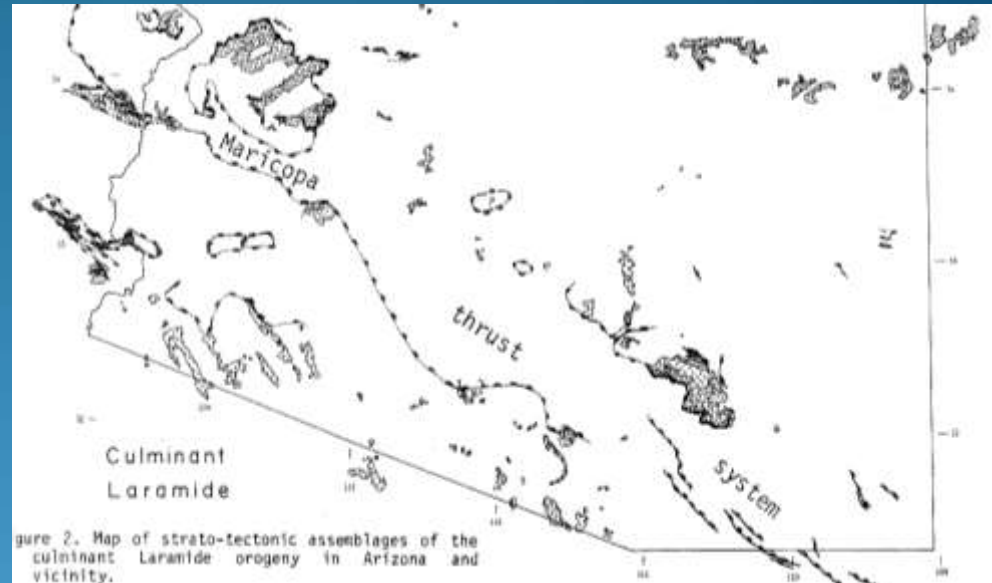


Latest Laramide – Wilderness (55-43 Ma)

Orogeny	Orogenic Phase	Age (Ma)	Age (period)	Arizona Magmatism	Alkalinity	Resources	Mining districts
	Late (Wilderness)	55-43	Early Tertiary	2-mica, garnet-muscovite granitic stocks, sills, dikes	Peralum. Calcic, Calc-alkalic	Au dissem. & qtz veins; W veins,	Oracle (Wilderness granite), Boriانا, Las Guijas, Gold Basin, Copperstone



Wilderness granite



W. Santa Catalina Mts. From El Conquistador

Laramide peraluminous mining districts

Orogeny	Orogenic Phase	Age (Ma)	Age (period)	Arizona Magmatism	Alkalinity	Resources	Mining districts
	Late (Wilderness)	55-43	Early Tertiary	2-mica, garnet-muscovite granitic stocks, sills, dikes	Peralum. Calcic, Calc-alkalic	Au dissem. & qtz veins; W veins,	Oracle (Wilderness granite), Boriانا, Las Guijas, Gold Basin, Copperstone



Copperstone Gold mine, La Paz Co.



Galiuro Orogeny - mid-Tertiary (43-13 Ma)

Orogeny	Orogenic Phase	Age (Ma)	Age (period)	Arizona Magmatism	Alkalinity	Resources	Mining districts
Galiuro	Late (Whipple)	18-13	Late Tertiary	volcanics & local epizonal stocks	Metaluminous Alkalic	Cu-Au-Ag in veins; epithermal Au-Ag veins	Oatman, Mammoth, Rowley, Swansea
	Middle (Datil)	28-18	Mid-Tertiary	alkali-calcic ignimbritic volcanics & plutons	Metaluminous Alkali-calcic	Pb-Zn-Ag F veins, replace.; epithermal	Silver (Red Cloud), Castle Dome, Stanley, Aravaipa
	Early (South Mountain)	30-22	Mid-Tertiary	calc-alkalic volcanics & plutons	Metalum. Calc-alkalic	Au +/- Cu-W veins & disseminated	Little Harquahala, Kofa
	Earliest (Mineta)	38-28	Mid-Tertiary	mostly within 'volcanic gap'	-	Uranium, clay, exotic copper	Ajo Cornelia, Copper Butte (from Ray)



Chiricahua Mts. Ash flow tuffs



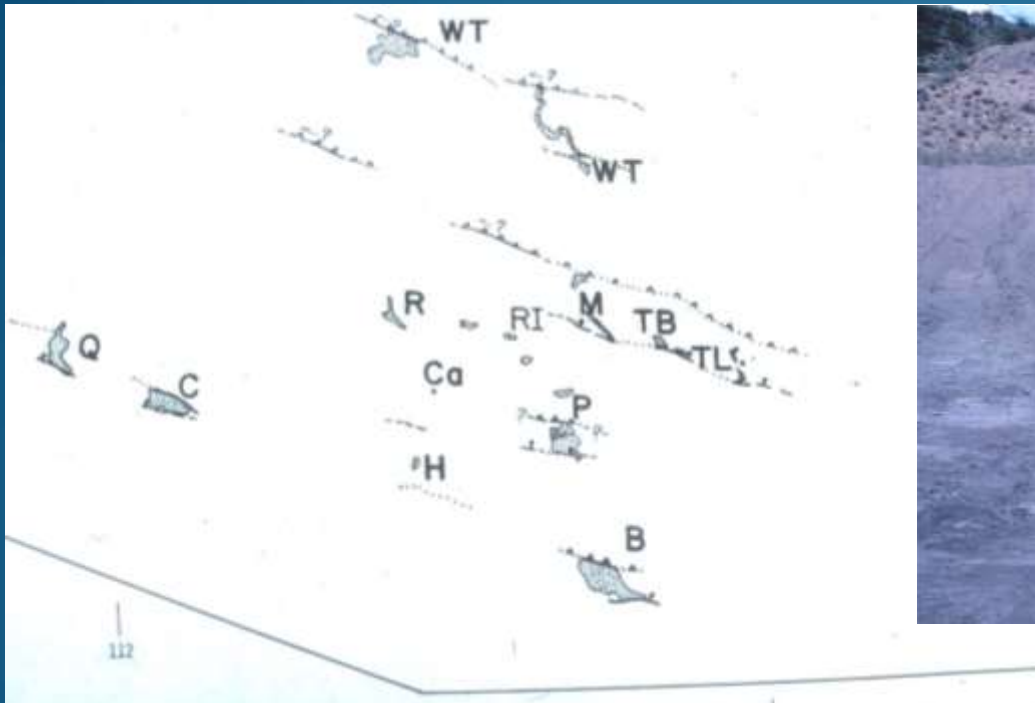
N. Tucson Mts.



Organ Pipe volcanics

Early Galiuro – Mineta (38-28 Ma)

Orogeny	Orogenic Phase	Age (Ma)	Age (period)	Arizona Magmatism	Alkalinity	Resources	Mining districts
	Earliest (Mineta)	38-28	Mid-Tertiary	mostly within 'volcanic gap'	-	Uranium, clay, exotic copper	Ajo Cornelia, Copper Butte (from Ray)



Pantano Clay, E. Tucson - 1987



Middle Galiuro – South Mtn. (30-22 Ma)

Orogeny	Orogenic Phase	Age (Ma)	Age (period)	Arizona Magmatism	Alkalinity	Resources	Mining districts
	Early (South Mountain)	30-22	Mid-Tertiary	calc-alkalic volcanics & plutons	Metalum. Calc-alkalic	Au +/- Cu-W veins & disseminated	Little Harquahala, Kofa

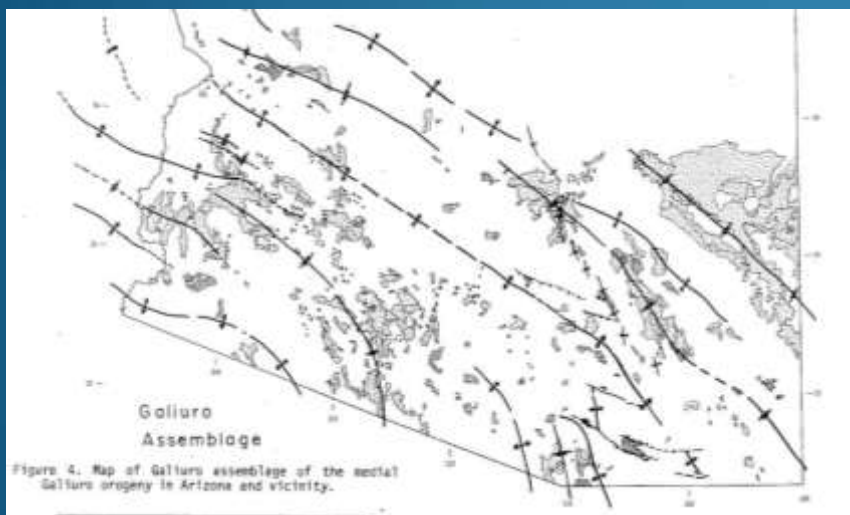
MID-TERTIARY



South Mountain, south Phoenix

Middle Galiuro – Datil (28-18 Ma)

Orogeny	Orogenic Phase	Age (Ma)	Age (period)	Arizona Magmatism	Alkalinity	Resources	Mining districts
Galiuro	Middle (Datil)	28-18	Mid-Tertiary	alkali-calcic ignimbritic volcanics & plutons	Metaluminous Alkali-calcic	Pb-Zn-Ag F veins, replace.; epithermal	Silver (Red Cloud), Castle Dome, Stanley, Aravaipa



Superstition Volcanics



Galiuro Volcanics

Red Cloud Mine

- **Alkali-calcic, mid-Tertiary**
- Irregular masses and vug linings of
 - argentiferous lead and zinc carbonates
 - with pyrolusite,
 - vanadinite,
 - wulfenite &
 - minor malachite,
 - partly altered argentiferous galena,
 - disseminated masses of silver chloride & bromide
- in a gangue of iron oxides, quartz, fluorite, calcite, gouge & brecciated wall rock
- Vein occurs in an irregular fault zone between Tertiary andesite breccia, dacite porphyry, rhyolite to dacitic tuffs & lapilli tuffs & Laramide granodiorite to quartz diorite intrusive



Red Cloud Mine



Wulfenite
Donor: Les & Paula Presmyk



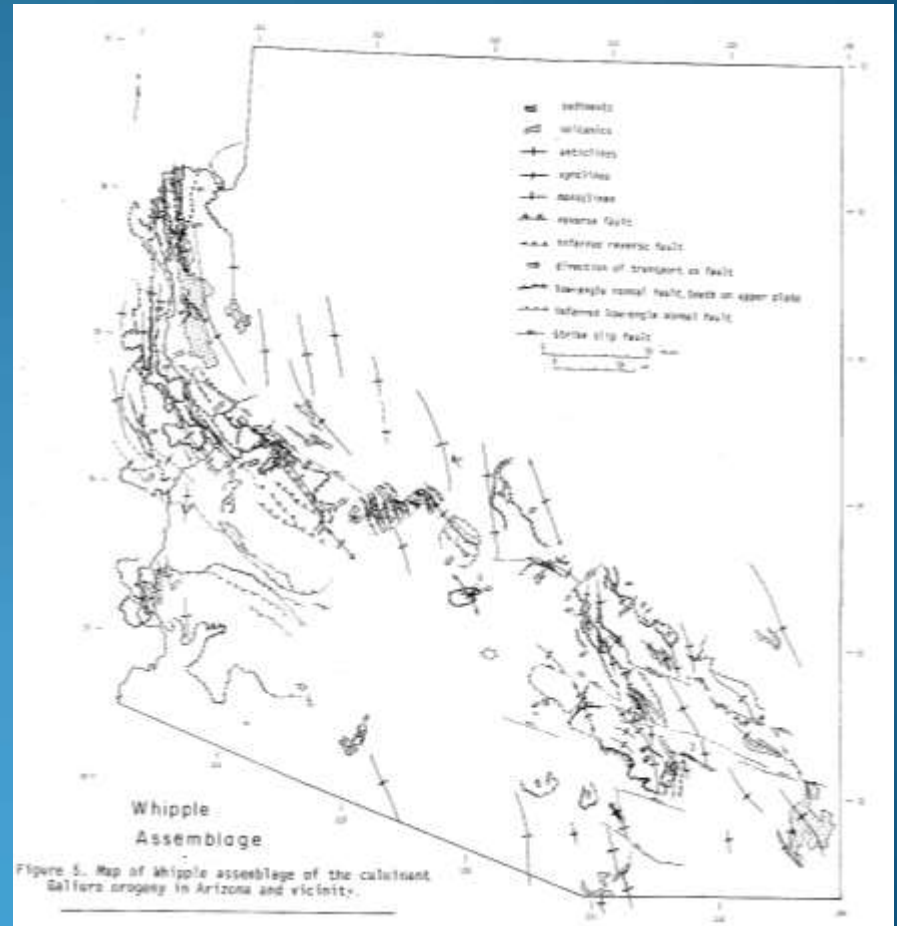
Vanadinite



cerussite

Late Galiuro – Whipple (18-13 Ma)

Orogeny	Orogenic Phase	Age (Ma)	Age (period)	Arizona Magmatism	Alkalinity	Resources	Mining districts
	Late (Whipple)	18-13	Late Tertiary	volcanics & local epizonal stocks	Metaluminous Alkalic	Cu-Au-Ag in veins; epithermal Au-Ag veins	Oatman, Mammoth, Rowley, Swansea



Mammoth-St. Anthony mine (Tiger)

Orogeny	Orogenic Phase	Age (Ma)	Age (period)	Arizona Magmatism	Alkalinity	Resources	Mining districts
	Late (Whipple)	18-13	Late Tertiary	volcanics & local epizonal stocks	Metaluminous Alkalic	Cu-Au-Ag in veins; epithermal Au-Ag veins	Oatman, Mammoth, Rowley, Swansea



Aerial photos courtesy of BHP Billiton, 2006

Mammoth-St. Anthony mine (Tiger)

- Wulfenite, vanadinite, gold in quartz, galena, sphalerite, anglesite, cerussite, and many oxidized minerals
- In west-northwest shear zones intruded by mid-Tertiary (22 Ma) rhyolite, with widest fissure veins occurring in quartz monzonite (Precambrian) most intensely shattered and brecciated
- Deposit was oxidized and faulted, then wulfenite and vanadinite were deposited with later oxidation



Donor: Leaverites

Mid-Tertiary – Santa Catalinas - Tiger – Mammoth-St. Anthony mine



Mid-Tertiary – Santa Catalinas - Tiger – Mammoth-St. Anthony mine



Rowley mine

- Quartz Alkalic - mid-Tertiary – 25-15 Ma



Donor: Floyd & Alice Getsinger



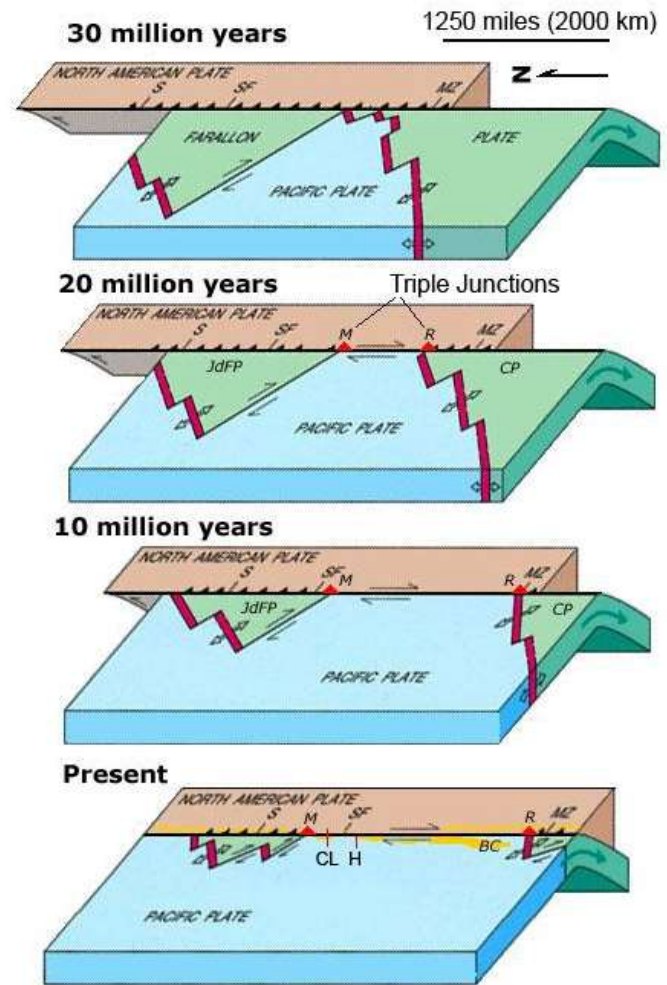
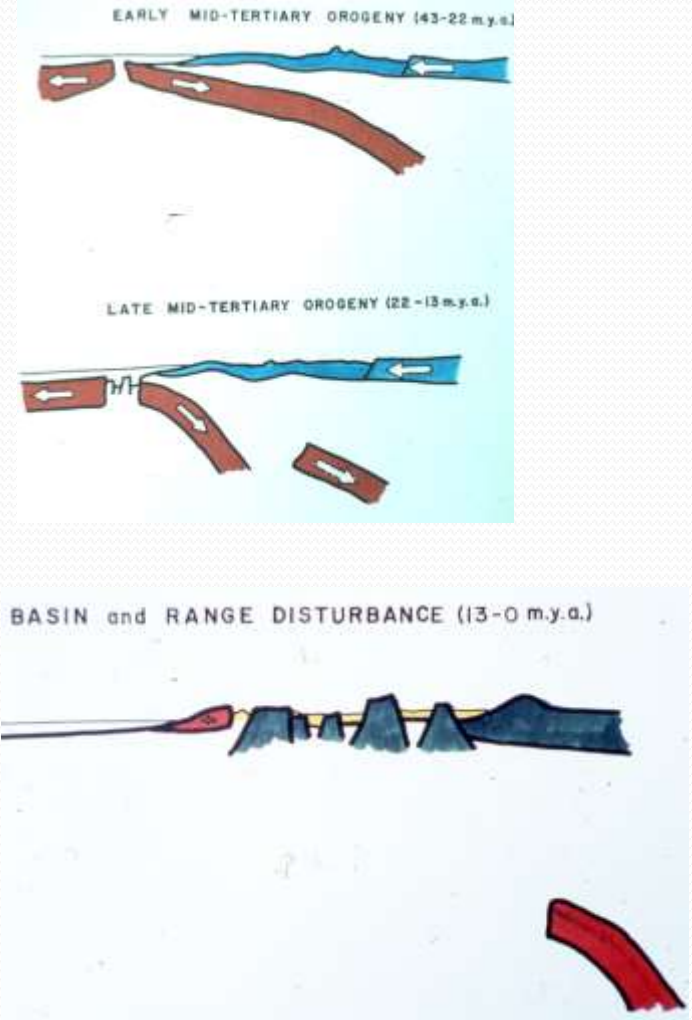
Donor: James Horner



Wulfenite and mimetite

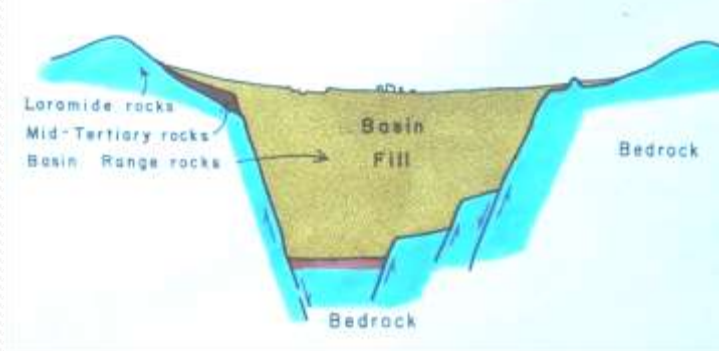
- Barite, wulfenite, cerussite, base-metal sulfides, with secondary minerals of cerussite-anglesite suite, wulfenite suite, caledonite suite, and vanadinite suite.
- In northwest fissure veins in mid-Tertiary andesite and rhyolite flows and dikes

San Andreas fault cuts off eastward-subducting plate

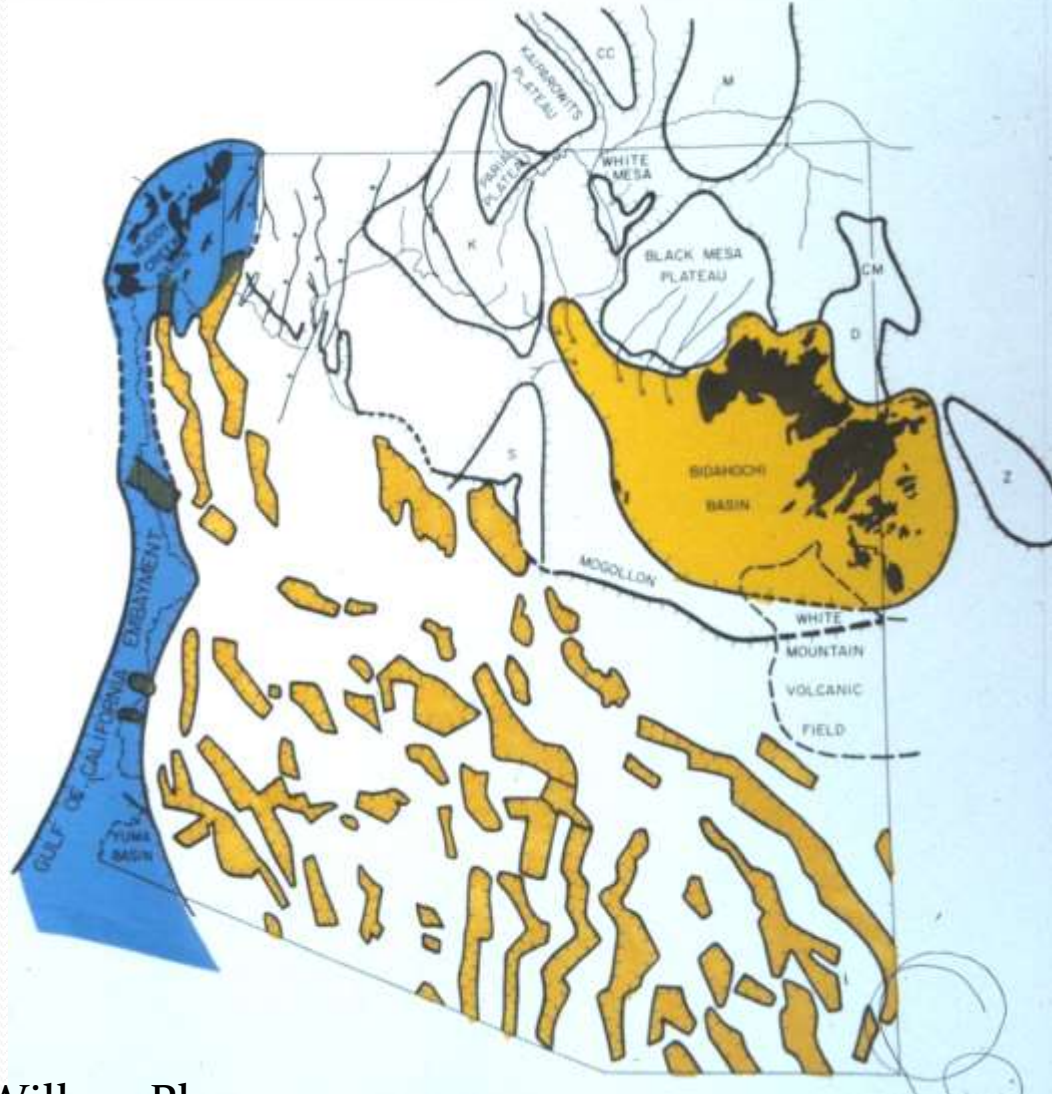


- Spreading center**—Arrows indicate direction of movement
- Subduction zone**—Sawtoen on upper plate
- Fault**—Arrows indicate direction of relative movement
- Triple Junction**

Basin and Range - Valleys filled with sand, gravel, clay, gypsum, & salt



- 1 LARAMIDE OR MID-TERTIARY VOLCANICS
- 2 MID-TERTIARY SEDIMENTS
- 3 BASIN FILL
- 4 PIEDMONT FACIES
- 5 VALLEY-CENTER FACIES
- 6 COARSE-GRAINED ALLUVIUM
- 7 TERRACES AND FLOODPLAIN



Willcox Playa

Industrial minerals - Late Cenozoic



Sand & gravel



Kalamazoo Clay - 1987



Gypsum rose



THENARDITE
Sodium Sulfate
Hex-H₂O
Camp Verde, Yavapai Co., AZ
Donor: Mark Wilson



Jan C. Rasmussen, Ph.D., R.G.



DRILL CORE through THENARDITE
Sodium Sulfate
Camp Verde, Yavapai Co., AZ
Donor: Nick Priznar
IMA 11008

April 6, 2013

www.janrasmussen.com

San Andreas – Basin & Range (13-0 Ma)

Orogeny	Orogenic Phase	Age (Ma)	Age (period)	Arizona Magmatism	Alkalinity	Resources	Mining districts
San Andreas	Basin & Range	13-0	Latest Tertiary	anhydrous basaltic volcanism	Metalum. Alkalic	Sand, gravel, salt, zeolites, gypsum Cu, Au, Ag in	San Francisco volcanic field, San Carlos olivine, Emerald Isle exotic Cu



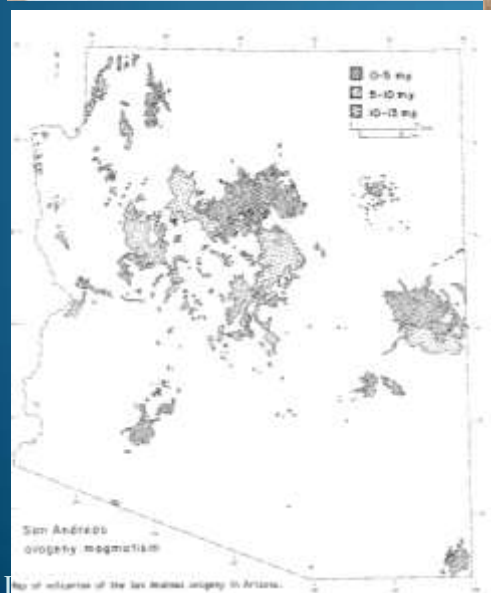
San Carlos AZ Peridot



Olivine in basalt, San Carlos



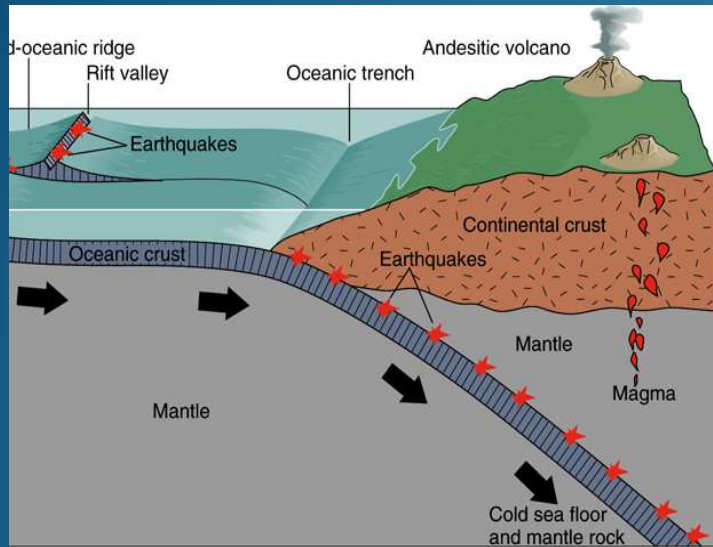
cinders



San Francisco Peaks, Flagstaff



Orogenies in Arizona



Orogeny	Orogenic Phase	Age (Ma)	Age (period)	Arizona Magmatism	Alkalinity	Resources	Mining districts
San Andreas	Basin & Range	13-0	Latest Tertiary	anhydrous basaltic volcanism	Metalum. Alkalic	Sand, gravel, salt, zeolites, gypsum	San Francisco volcanic field, San Carlos olivine, Emerald Isle exotic Cu
Galiuro	Late (Whipple)	18-13	Late Tertiary	volcanics & local epizonal stocks	Metaluminous Alkalic	Cu-Au-Ag in veins; epithermal Au-Ag veins	Cobman, Mammoth, Rowley, Swansea
	Middle (Dabell)	28-18	Mid-Tertiary	alkali-calcic ignimbritic volcanics & plutons	Metaluminous Alkali-calcic	Pb-Zn-Ag F veins; replace.; epithermal	Silver (Red Cloud), Castle Dome, Stanley, Aravaipa
	Early (South Mountain)	30-22	Mid-Tertiary	calc-alkalic volcanics & plutons	Metalum. Calc-alkalic	Au +/- Cu-W veins & disseminated	Little Harquahala, Kofa
	Earliest (Mineta)	38-28	Mid-Tertiary	mostly within 'volcanic gap'	-	Uranium, clay, exotic copper	Ajo Comelia, Copper Butte (from Ray)
Laramide	Late (Wilderness ss)	55-43	Early Tertiary	2-mica, garnet-muscovite granitic stocks, sills, dikes	Peralum. Calcic, Calc-alkalic	Au dissem. & qtz veins; W veins.	Oracle (Wilderness granite), Boriana, Las Guijas, Gold Basin, Copperstone
	Middle (Morenci)	65-55	Cretaceous-Tertiary	granodiorite-quartz monzonite porphyry stocks, NE to ENE-striking dike swarms	Metaluminous Calc-alkalic	large disseminated porphyry Cu systems, local skarns & veins, fringing Zn-Pb-Ag	Ajo, Ray, Christmas, San Manuel, Mineral Park, Pima, Bagdad, Silver Bell, Globe-Miami, Morenci, Superior
	Early (Tombstone)	85-65	Late Cretaceous	qtz. monz. porph. stocks; ash flows	Metalum. Alkali-calcic	Pb-Zn-Ag veins & replacement deposits	Tombstone, Tyndall (Glove), Washington Camp, Salero
	Earliest (Hillsboro)	89-85	mid-Cretaceous	Volcanics, small stocks	Metalum. Alkalic	Cu-Au hydrothermal	Hillsboro, NM
Sevier		145-89	mid-Cretaceous			Sedimentary rocks	Bisbee Group sediments
Nevadan	Late	160-145	Late Jurassic	volcanics			
	Middle	205-160	Late & Middle Jurassic	Canelo Hills volcanics; plutonic rocks	Metalum. Alkalic	porphyry Cu-Au at Bisbee, Gleeson	Warren (Bisbee mine), Turquoise (Courtland-Gleeson)
	Early	230-205	Late Triassic	Fluid flow thru sedimentary rocks	Metalum. Alkalic	Uranium, vanadium, copper	Orphan, Grandview, Monument Valley
Alleghenian (Ouachita)		325-220	Miss. - Triassic	None	-	U in sed. rocks	Payson uranium
Acadian/Caledonian		410-380	Devonian	None	-	Limestone	
Taconic		490-445	Cambrian - Ord.	None	-		
Grenville		1200-900	Late Middle Proterozoic - Early Late Proterozoic	basalt flows, diabase dikes	Metalum. Alkalic	Serpentine asbestos	Sierra Ancha uranium, Chrysotile (Salt R. Canyon)
"Oracle/Ruin"		1440-1335	Middle Proterozoic	K-feldspar megacrystic or porphyritic granites	Peralum. Calc-alkalic, Alkali-calcic	Pegmatites & greisens - Be, Li, Ta-Nb, U & W	White Picacho, Tungstona, Four Peaks
Mazatzal		1750-1600	Late Early Proterozoic	Basalt & rhyolite metavolc., schist	Metalum. Calcic	Cu-Zn-Ag VMS	Old Dick (Bruce)
Yavapai		1800-1775	Late Early Proterozoic	Andesite, schist, metarhyolite	Metalum. Calcic	Cu-Zn-Au VMS, Cu-Zn-Ag	Big Bug (Iron King), Verde (Jerome)
Penokean/Hudsonian		2000-1800	Middle Late Proterozoic	Schist, banded cherty iron formation	Metalum. Calcic	BIF (Banded iron formation)	Pikes Peak Iron