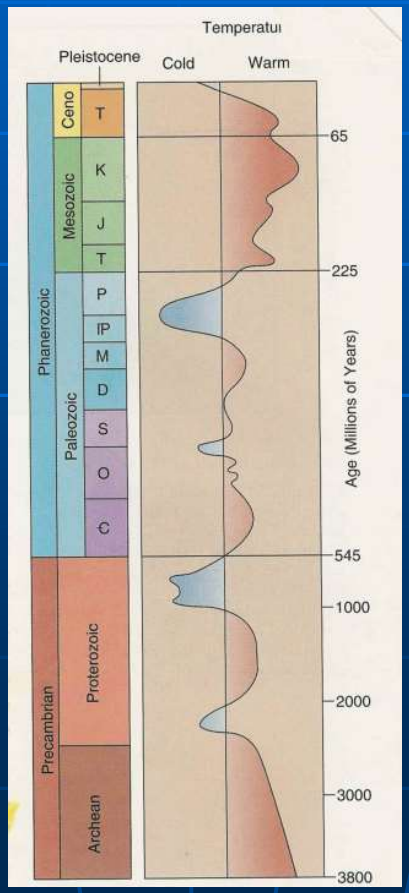
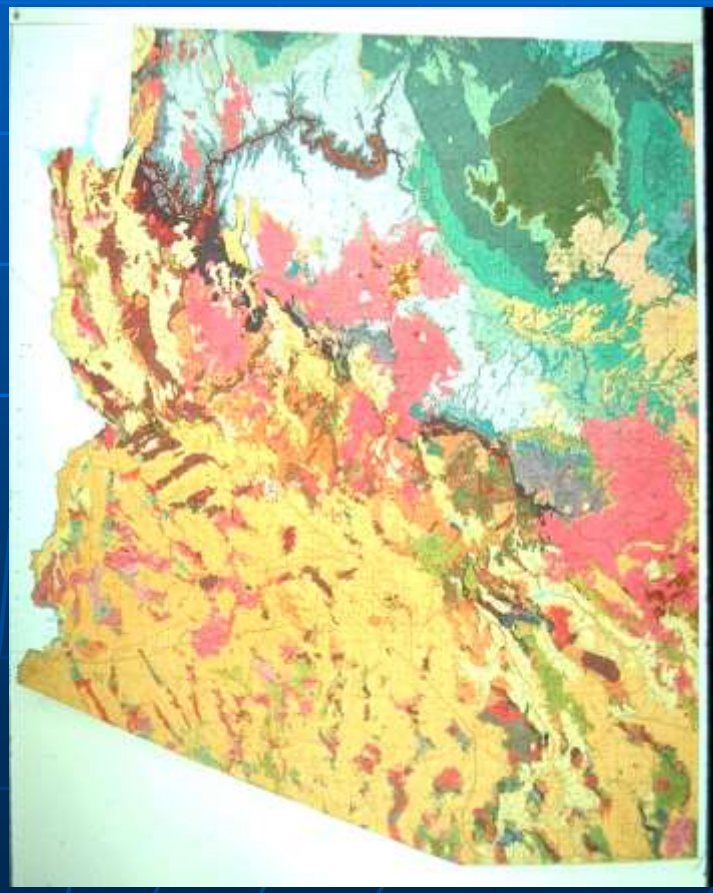
Tucson Geologic History: Mesozoic (251 – 65.5 Ma)

Dr. Jan C. Rasmussen
www.janrasmussen.com





Arizona physiography

- Depends on plate tectonics through geologic history
- Big environmental changes through geologic time
- Seas in, seas out – Paleozoic
- Mountain building – Mesozoic, Cenozoic
- Warm periods and ice ages

Arizona Physiographic Provinces

Colorado Plateau Province

- canyons
- horizontal sediments
- broad warping

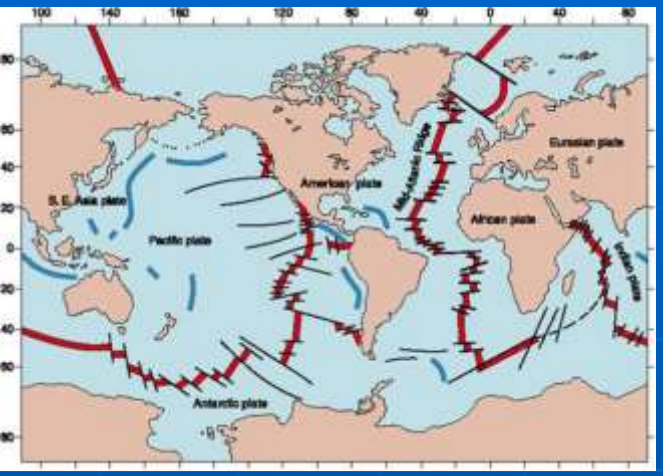
Transition or Central Highlands Province

- lots of faulting
- mostly mountains
- rugged terrain (high relief)

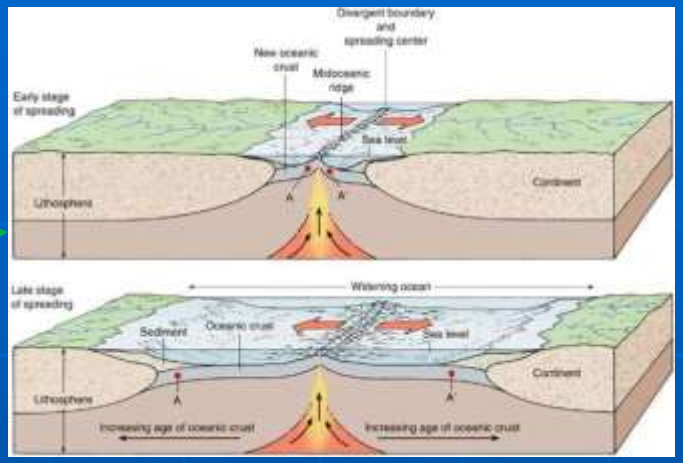
Basin & Range Province

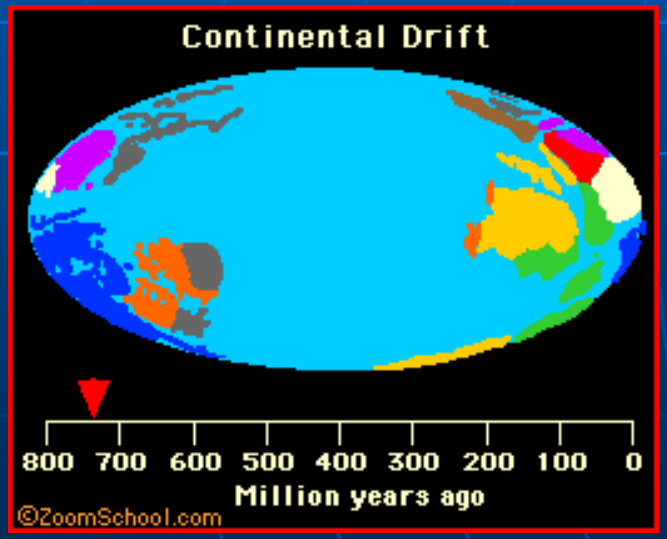
- fault block mountains
- broad alluvial valleys
- sand, clay, salt & gravel - fill up to 10,000 feet thick

Plate Tectonics

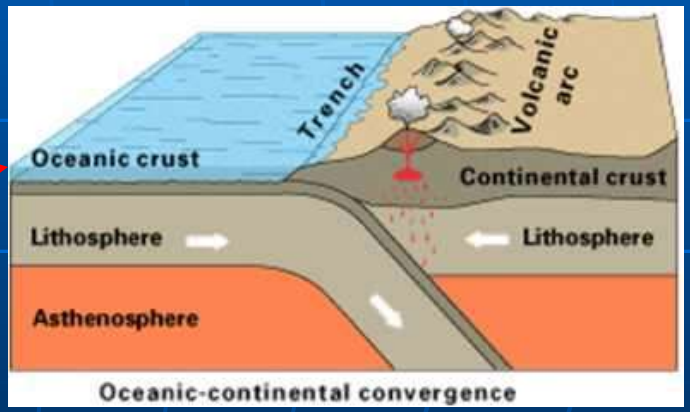


Sea floor spreading and mid-ocean ridge volcanism

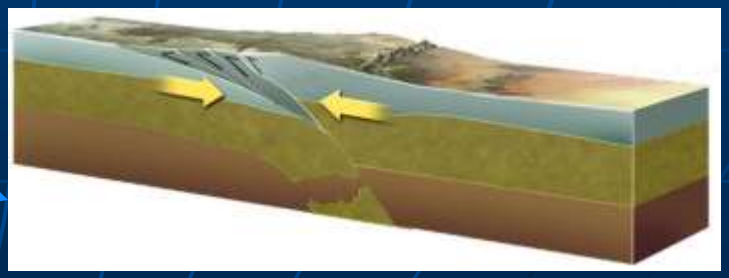




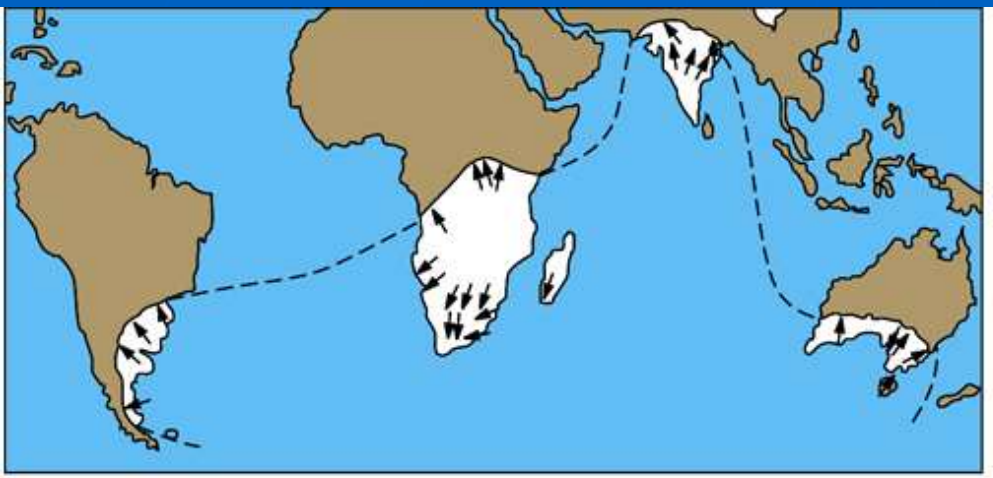
Subduction, Volcanoes, Mountains



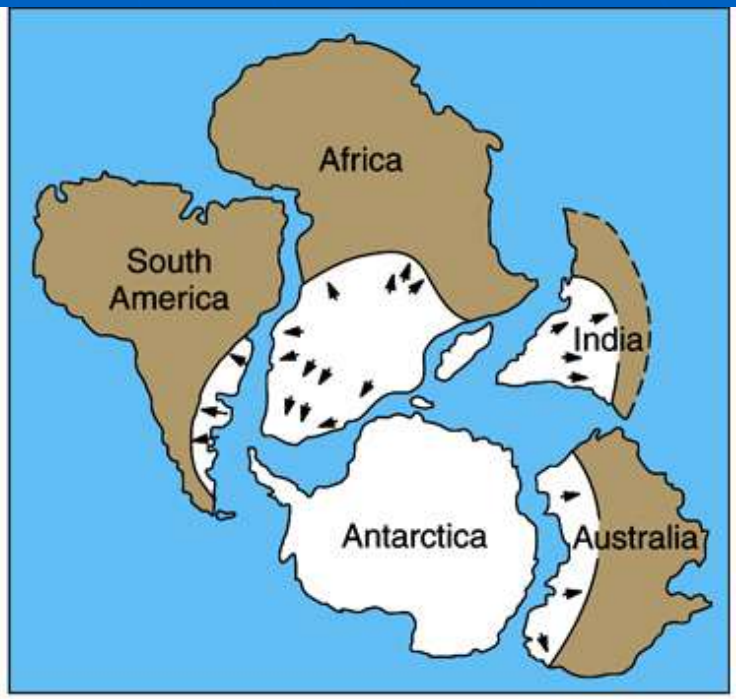
Continent-continent collision and very tall mountains



Ice Age at end of Paleozoic – continents assembled at S. Pole



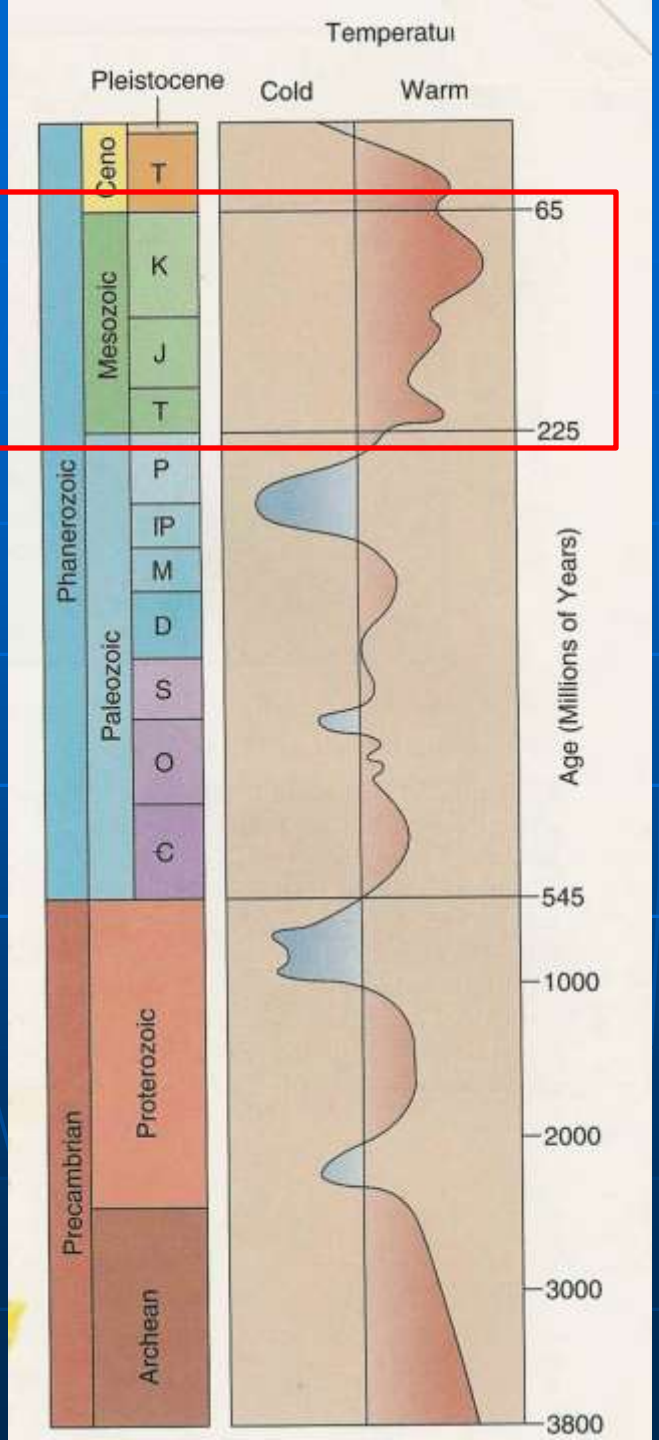
A



B

Source: McGraw Hill, Plummer et al., Physical Geology

Temp. & Geologic Time Scale



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Phanerozoic	Cenozoic	Quaternary		Holocene		0.01
				Pleistocene	Late	0.8
					Early	1.8
		Tertiary	Neogene	Pliocene	Late	3.6
					Early	5.3
				Miocene	Late	11.2
					Middle	16.4
					Early	33.7
				Oligocene	Late	28.5
					Early	33.7
			Paleogene	Eocene	Late	41.3
					Middle	49.0
					Early	54.8
				Paleocene	Late	61.0
					Early	65.0
	Mesozoic	Cretaceous		Late		99.0
				Early		144
		Jurassic		Late		159
				Middle		180
				Early		206
		Triassic		Late		227
				Middle		242
				Early		248
	Paleozoic	Permian		Late		256
				Early		290
		Pennsylvanian				323
		Mississippian				354
		Devonian		Late		370
				Middle		391
				Early		417
		Silurian		Late		423
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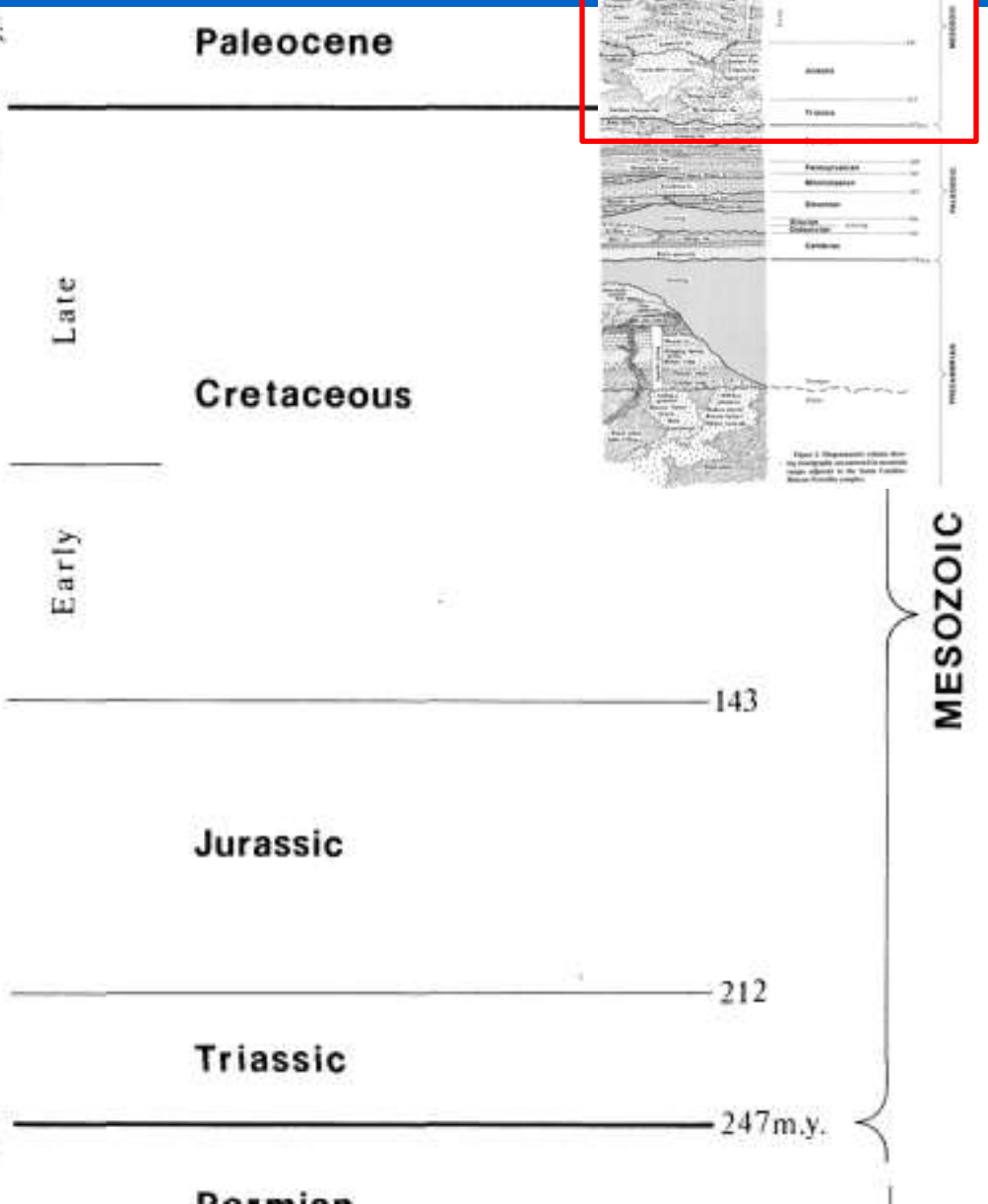
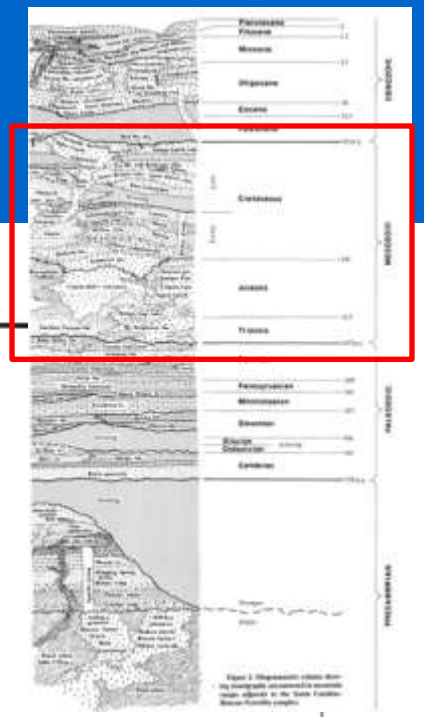
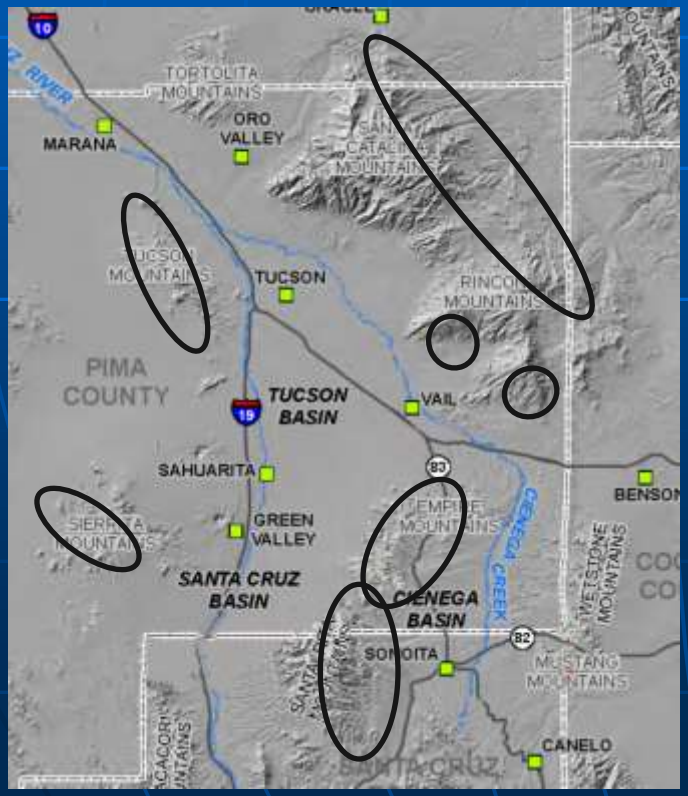
				Middle		470
				Early		490
		Cambrian		D		500
				C		512
				B		520
				A		543
	zoic	Late				

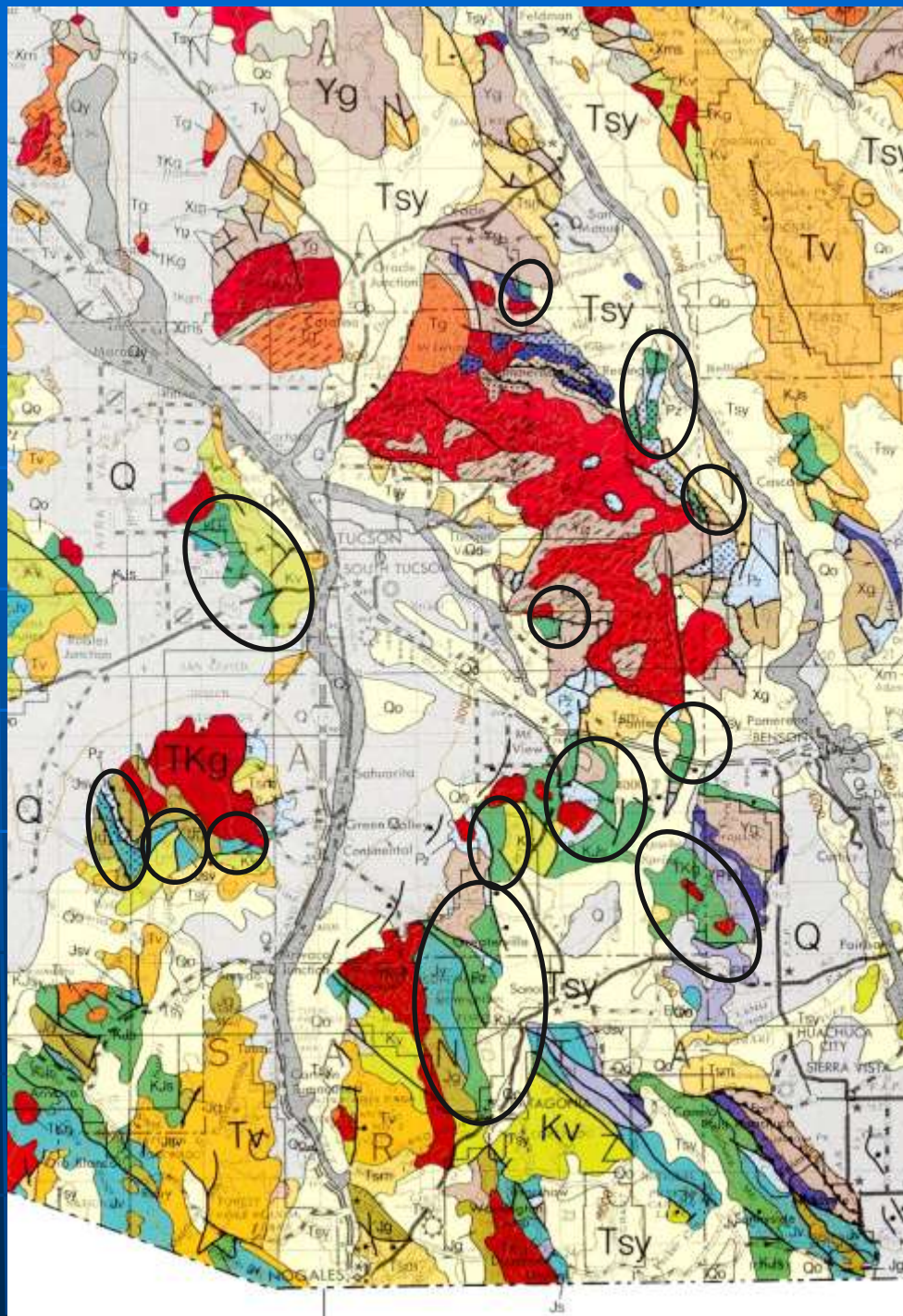
Mesozoic Formations near Tucson



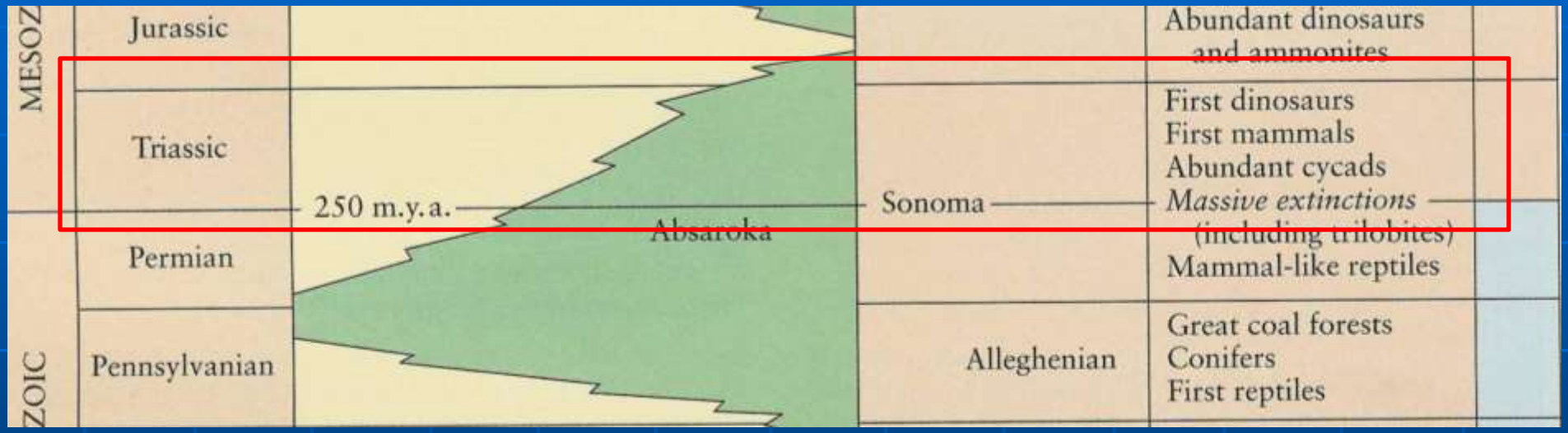


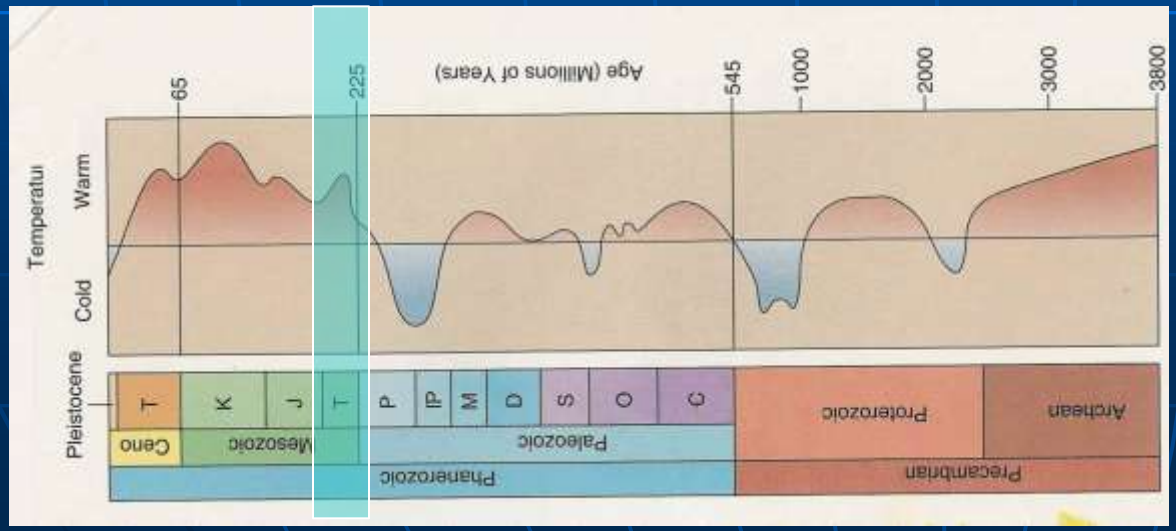
Mesoozoic outcrops around Tucson



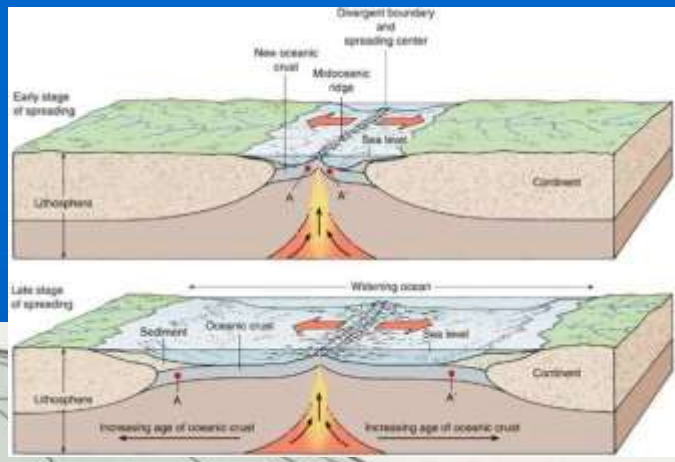


Triassic (251-199.6 Ma)
(Ma = million years ago)





Triassic plate tectonics



Baltica

Laurentia

N. China

S. China

Africa

Arabia

South America

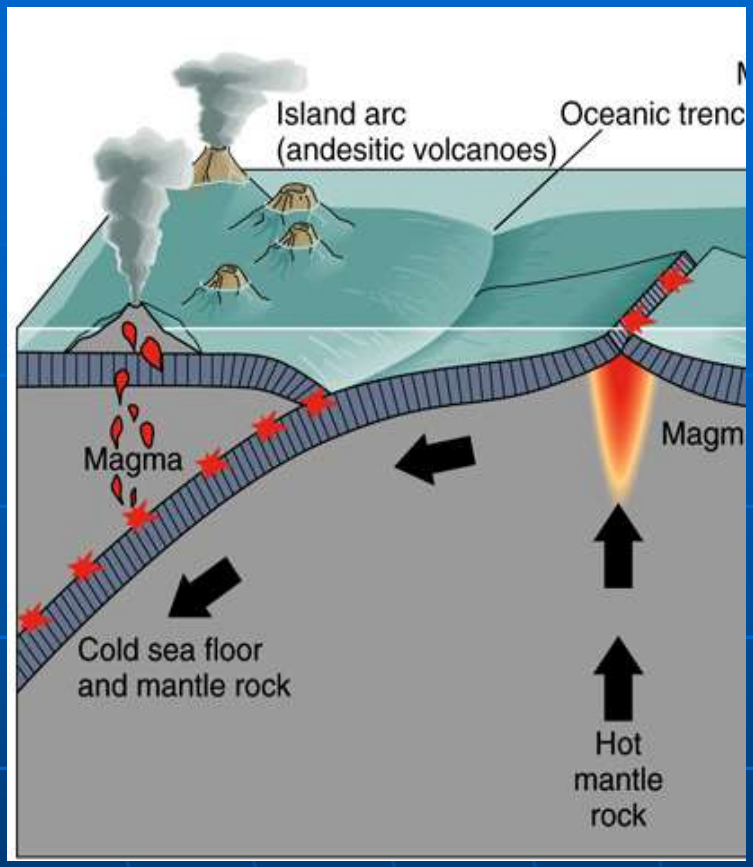
India

Australia

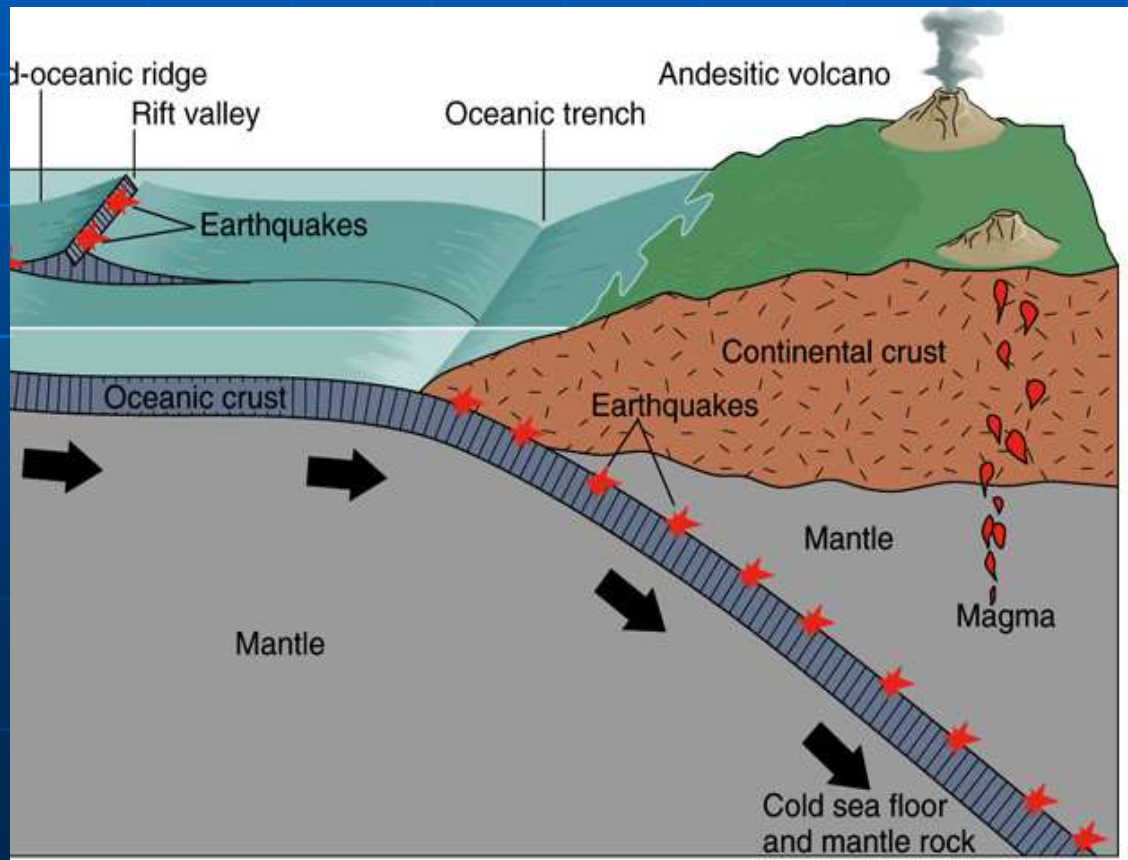
Antarctica

FIGURE 11–1 Paleogeographic reconstruction of the world about 180 million years ago, when the break-up of Pangea was beginning. (After Scotese, C. R. and McKerrow, W. S. 1990. Paleogeography and Biogeography, *Geol. Soc. London Mem. 12:1–21.*)

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



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



Paleozoic – Arizona on trailing edge of N.Am. Continent – calm seaways

Triassic paleogeography

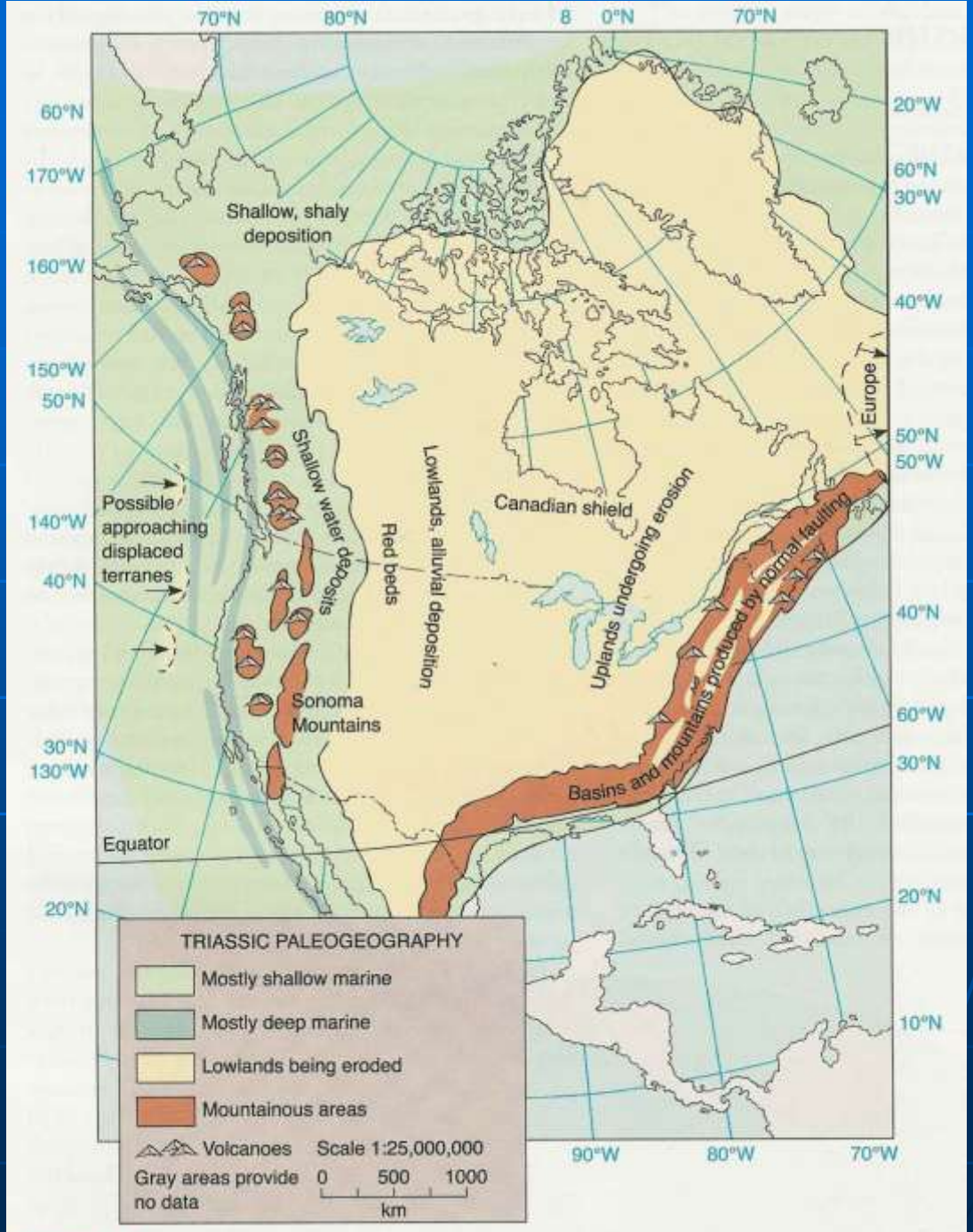
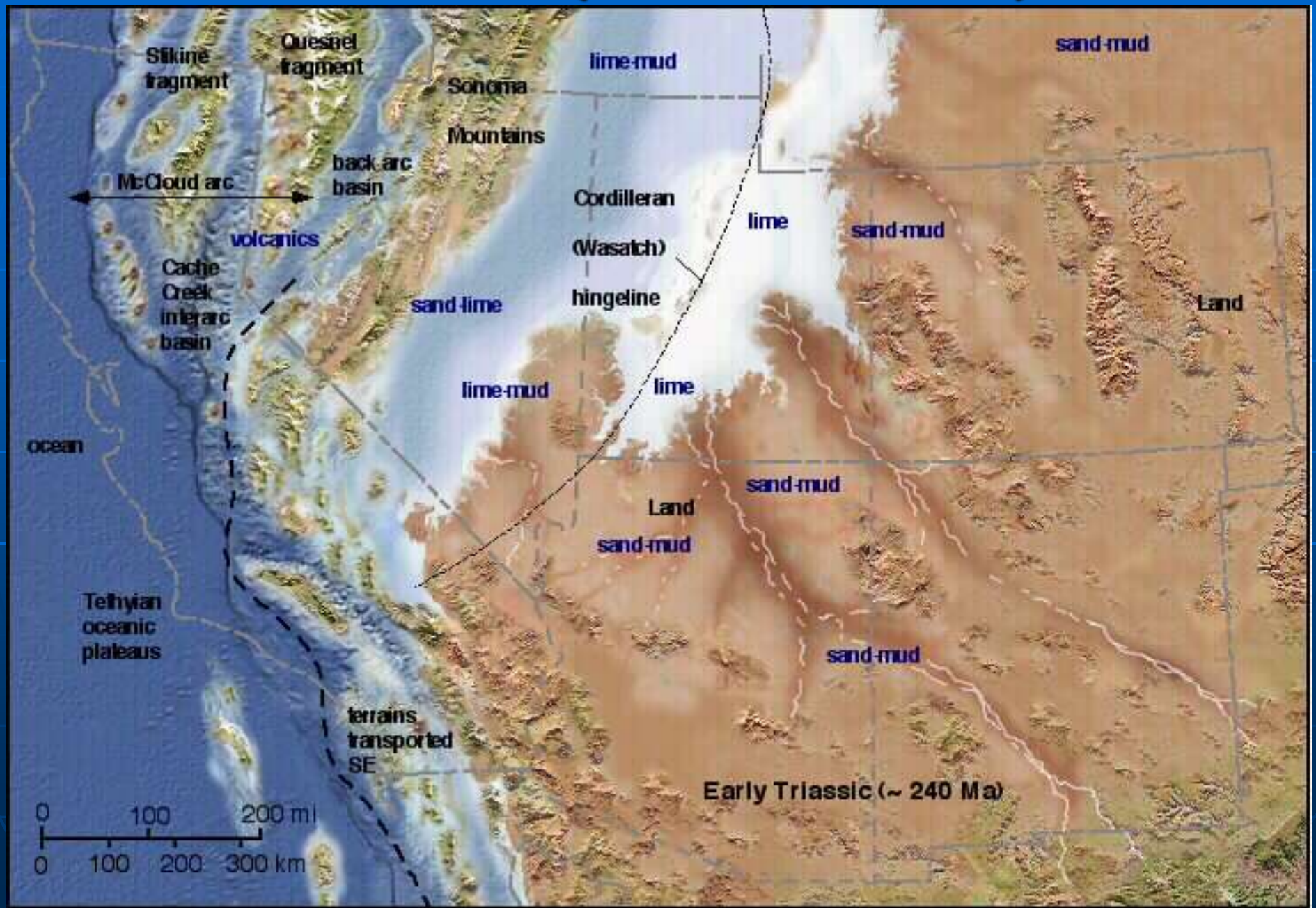
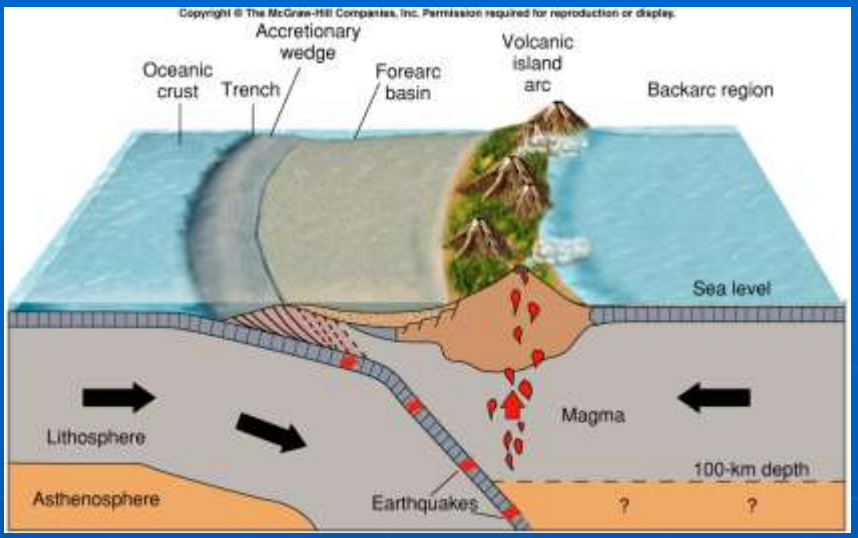


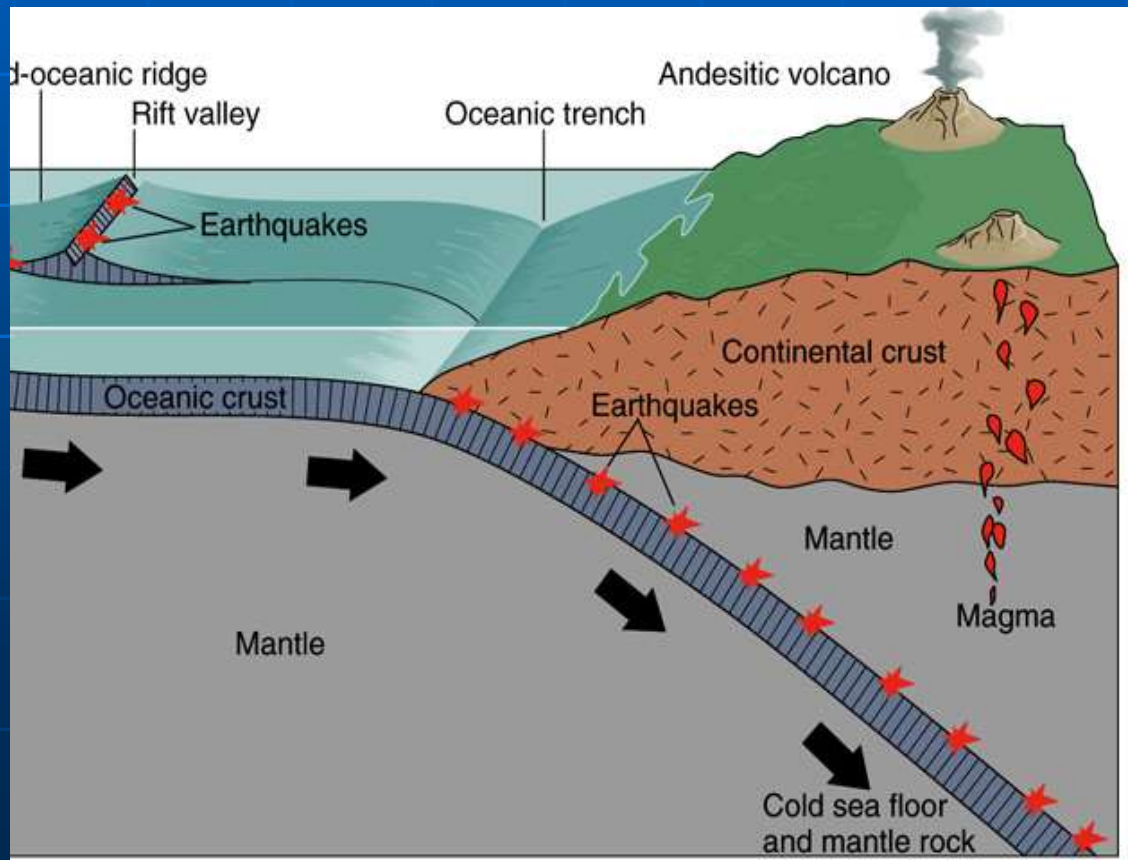
FIGURE 11–3 Generalized paleogeographic map for the Triassic of North America.

Triassic (251-199.6 Ma)



Jurassic volcanic & intrusive arc

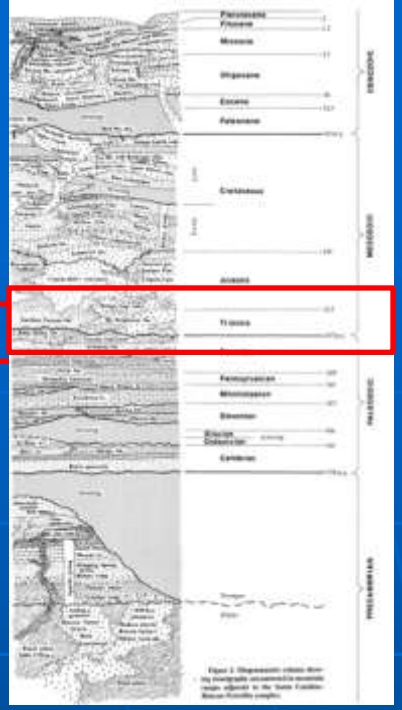


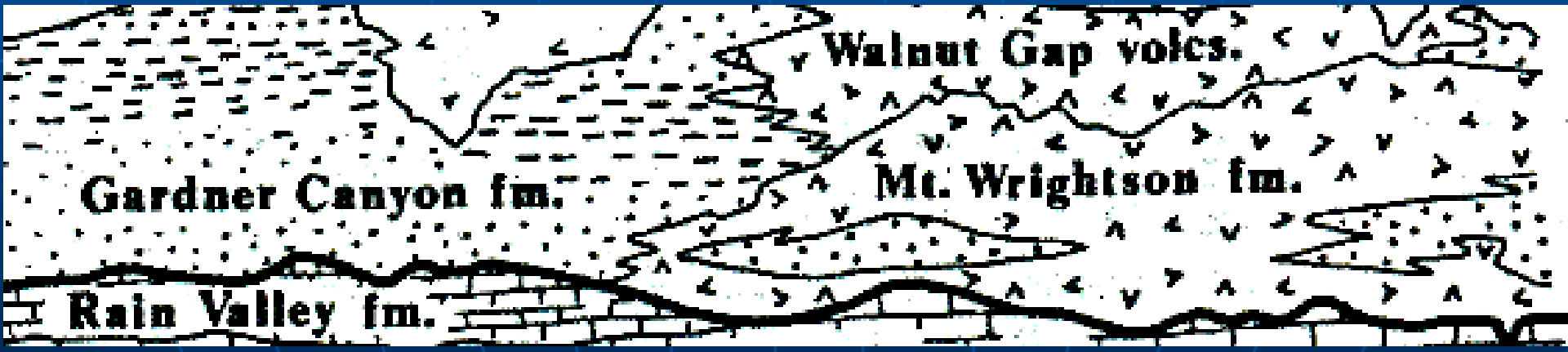


Mesozoic – Santa Rita Mts.

- Mt. Wrightson and Mt. Hopkins looking East from Green Valley

Triassic Formations near Tucson





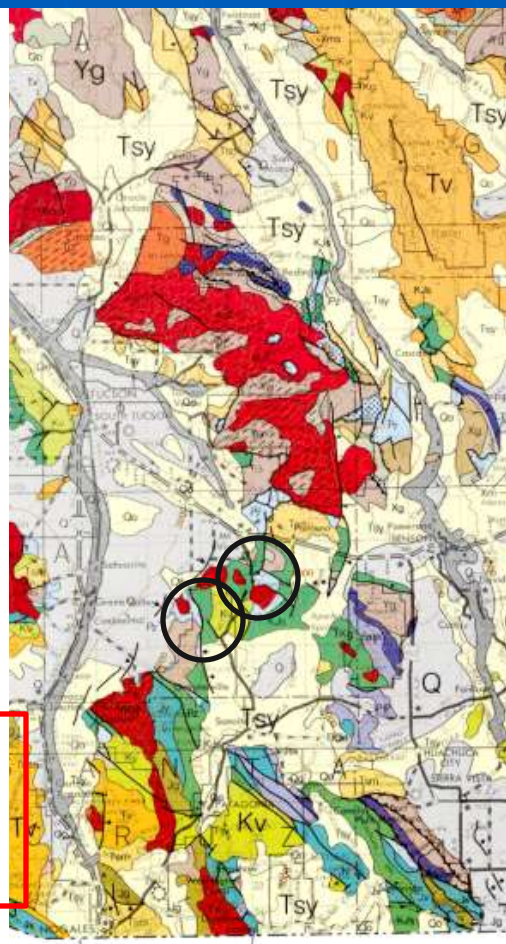
Early Mesozoic – Triassic (251.5-199.6 Ma)

Santa Rita Mts. – volcanics, sediments

Gardner Canyon Fm. volcanics, mudstone, conglomerate (192 Ma)

Mt. Wrightson Fm. volcanics & sandstone (sand dunes) (220 Ma)

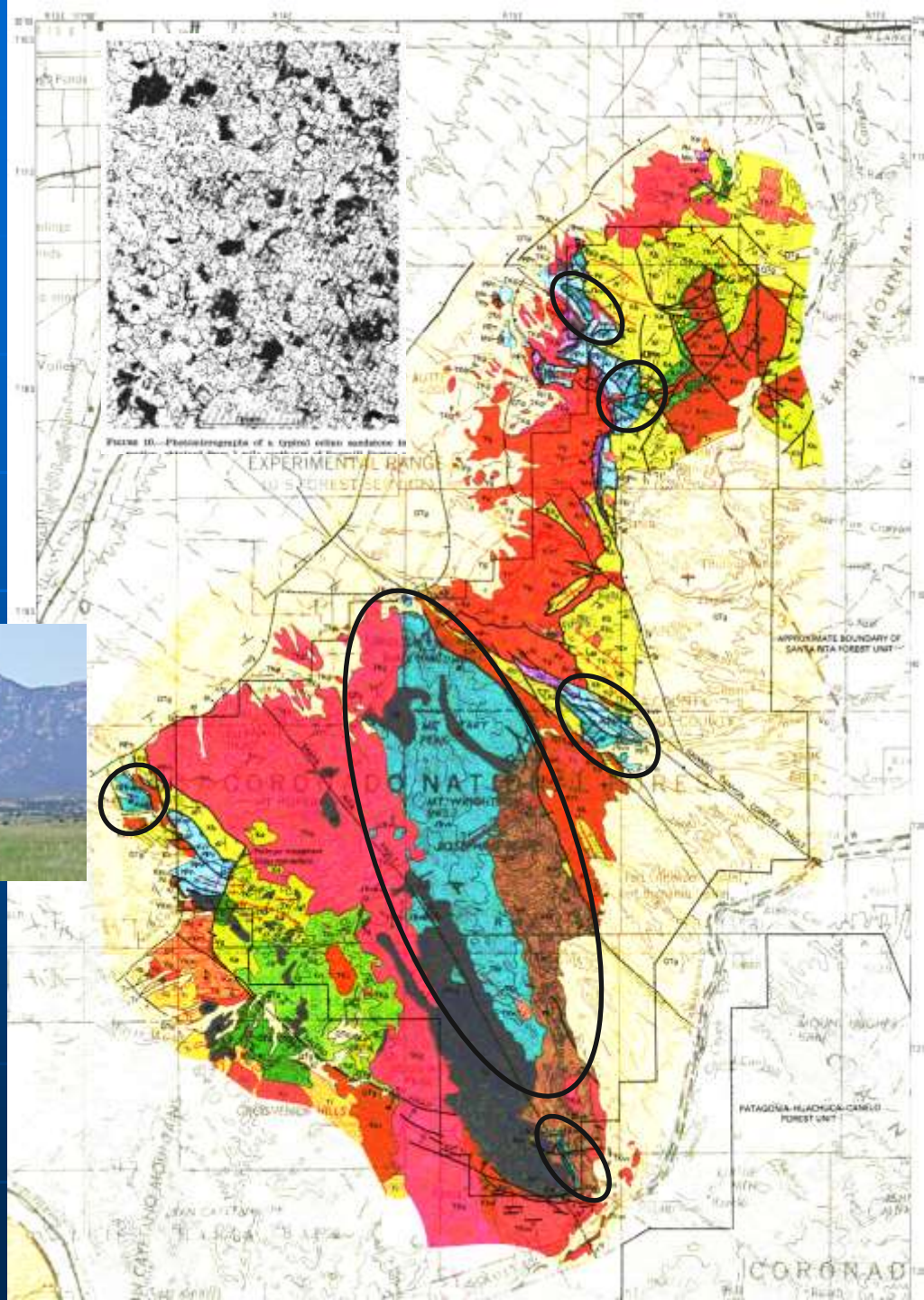
Age	Group	Formation	Thickness (feet)	Subdivisions	Description
Paleocene(?)		Gringo Gulch Volcanics			Rhyolitic volcanics and clastic rocks.
		Unconformity (major intrusions)			
Late Cretaceous		Salero Formation	5,000±	Upper member	Sedimentary and volcanic rocks; 2,500± ft.
				Arkose member	Arkose and conglomerate largely facies of welded-tuff member; 500± ft.
				Welded-tuff member	Rhyodacite welded tuff; 1,200+ ft. 72.5± 2.2 m.y.
				Exotic-block member	Dacitic volcanics containing large exotic blocks; 1,000± ft.
				Lower member	Dacitic volcanics; 400+ ft.
		Unconformity			
		Fort Crittenden Formation	4,200–5,800+	Rhyolitic tuff member	Tuff intercalated in upper red conglomerate; 0–650 ft.
				Upper red conglomerate member.	Volcanic conglomerate to siltstone; 1,400+ ft.
				Brown conglomerate member.	Arkosic conglomerate to siltstone; 2,000+ ft.
				Lower red conglomerate member.	Volcanic conglomerate to siltstone; 800–1,200 ft.
				Shale member	Fossiliferous shale, and sandstone; 4–550+ ft.
		Unconformity			
Early Cretaceous	Bisbee Group (7,500+ ft)	Turney Ranch Formation	1,500+		Sandstone and red siltstone.
		Shellenberger Canyon Formation	1,600+		Siltstone and arkose.
		Apache Canyon Formation	1,500–2,000		Arkose, siltstone, and limestone lenses.
		Willow Canyon Formation	2,200+		Arkose and conglomerate.
		Glance Conglomerate	0–1,500+		Limestone-and-granite cobble conglomerate.
		Unconformity			
		Bathtub Formation	1,500–2,300	Upper member	Dacite volcanics and tuffaceous sandstone; 0–1,500 ft.
				Middle member	Rhyolite to andesite volcanics; 800–1,500 ft.
				Lower member	Conglomerate and volcanic sandstone; 700± ft.
		Minor unconformity			
		Temporal Formation	1,000–2,000	Upper member	Conglomerate and rhyolite volcanics; 600–1,000 ft.
				Middle member	Rhyolite to latite volcanics and conglomerate; 100–400 ft.
				Lower member	Rhyolitic to dacitic volcanics and fanglomerate; 200–1,300 ft.
		Unconformity (major granite intrusion)			
Early Jurassic and Late Triassic		Canelo Hills(?) Volcanics	600+		Arkose, tuffaceous sandstone, tuff, and conglomerate. 173±7 m.y.
		Disconformity			
Triassic		Gardner Canyon Formation	1,000+	Mudstone member	Red mudstone, dacite volcanics and conglomerate. 192±20 m.y.
				Siltstone member	Red siltstone and chert pebble conglomerate.
		Unconformity			
		Mount Wrightson Formation	8,500±	Upper member	Eolian sandstone, andesitic to rhyodacitic volcanics; 2,000+ ft.
				Middle member	Rhyolitic to latitic volcanics, trace of clastic rocks; 5,000± ft. 220±30 m.y.
				Lower member	Dacitic to andesitic volcanics, and sandstone; 1,500+ ft.
		Inferred unconformity			
Permian		Rainvalley Formation			Marine limestone, dolomite, and sandstone.



Early Mesozoic – Triassic

(251.5-199.6 Ma)

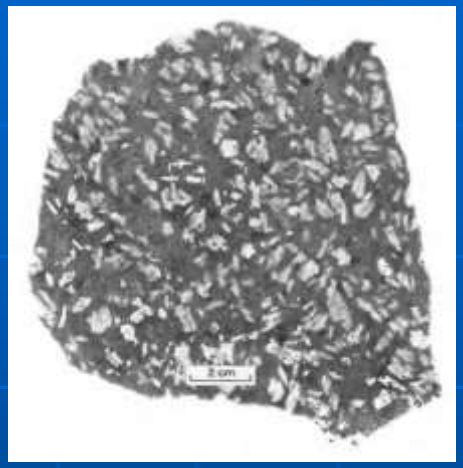
Santa Rita Mts. – volcanics, sediments



Gardner Canyon Fm. Volcanics, Mudstone (192 Ma)

Mt. Wrightson Fm. Volcanics & sandstone (sand dunes) (220 Ma)

Triassic volcanics & Sedimentary Rocks – Mt. Wrightston Fm.



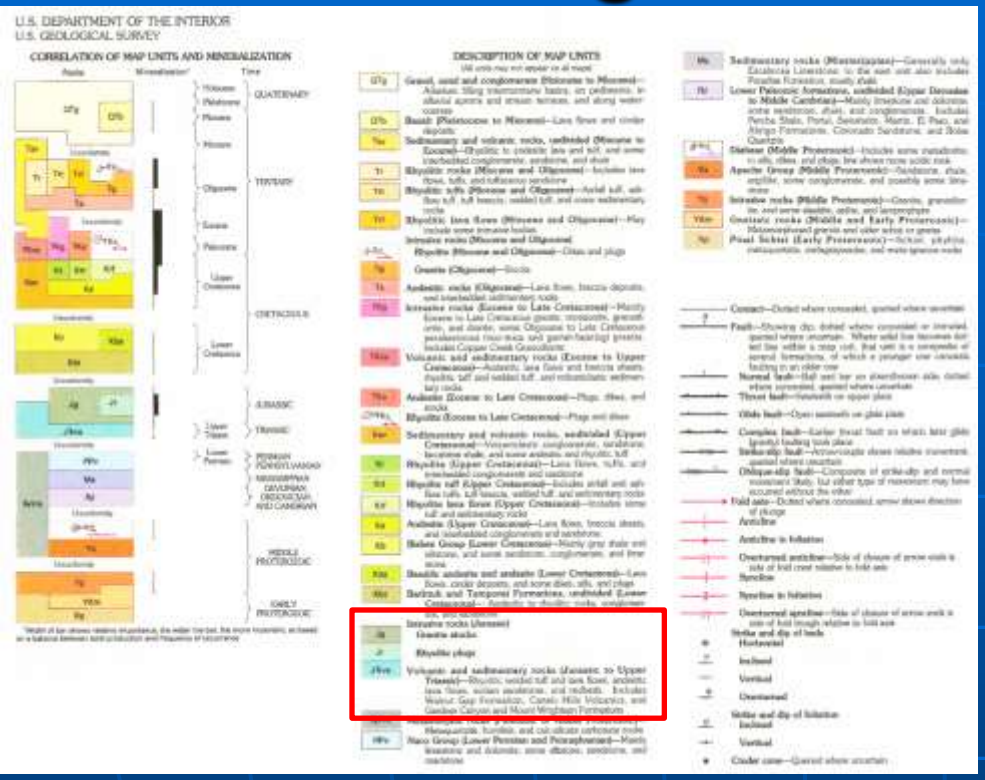
Porphyritic andesite

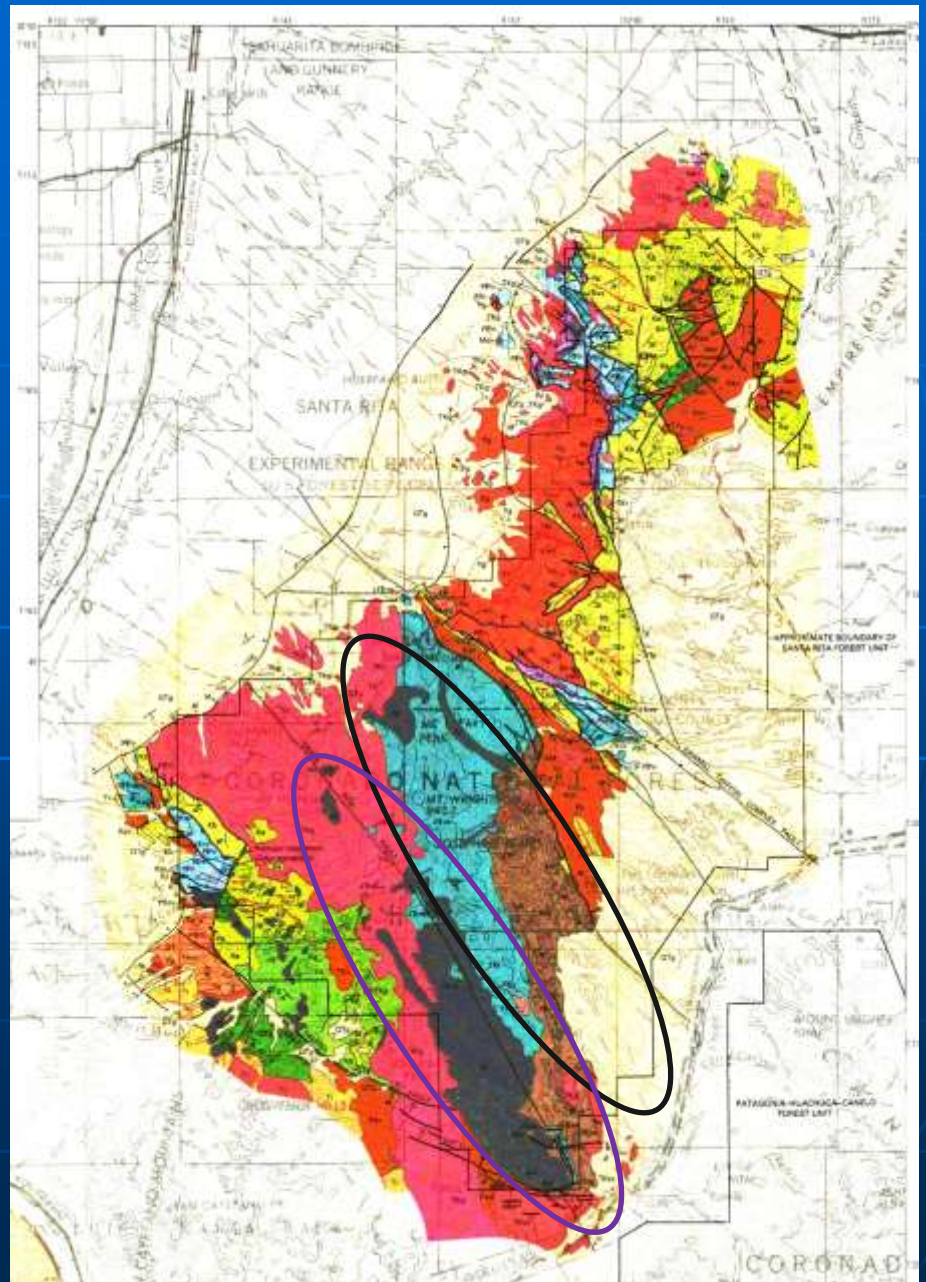
Lower = volcanics and sandstone
Middle = rhyolite volcanics 220 Ma
Upper = Eolian sandstone (sand dunes) and volcanics

Gardner Canyon Fm. – mudstone mbr.

- Mt. Wrightson and Mt. Hopkins looking East from Green Valley

Jurassic granite – Santa Rita Mts.



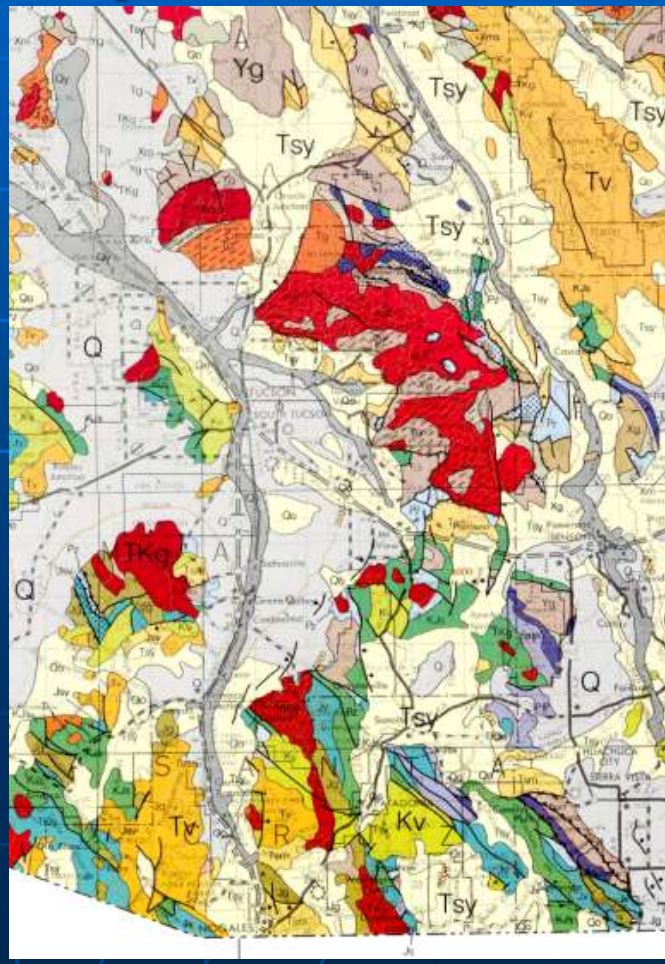


Jurassic Granite – purple oval

Canelo Hills Volcanics - sandstone, tuff, conglomerate (173 Ma) – black oval

Source: Drewes, 1996, USGS Bull. 2083, plate 4

Early Mesozoic – Triassic Santa Catalina Mts. – none left – all eroded during later periods



Early Mesozoic – Triassic
Tucson Mts. – Recreation Redbeds

Petrified Forest Fm. – late Triassic

Ash from volcanoes in southern Arizona spread to northern Arizona

Triassic Reptiles

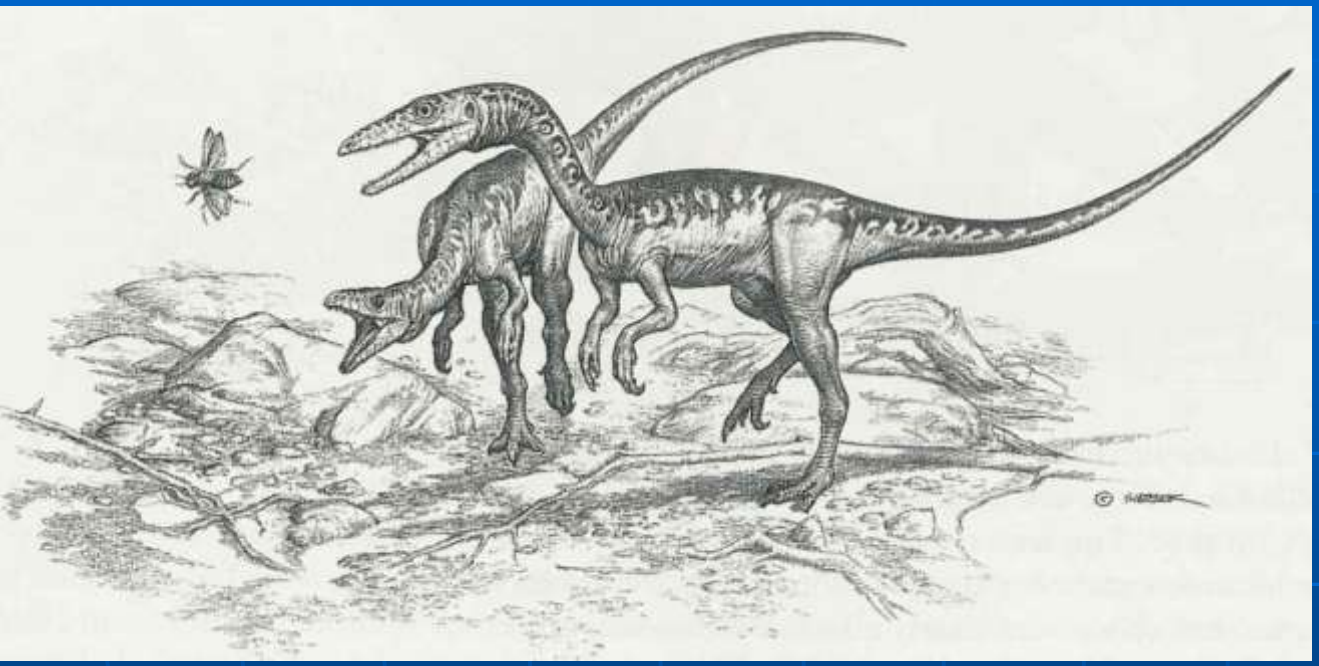


FIGURE 12-21 The small, agile theopod *Coelophysis* lived about 220 million years ago, during the Late Triassic. *Coelophysis* was about 3 meters in length. These fast, agile, bipedal predators may have pursued their prey in packs, and there is evidence that they occasionally even ate juveniles of their own species. (*Copyright*

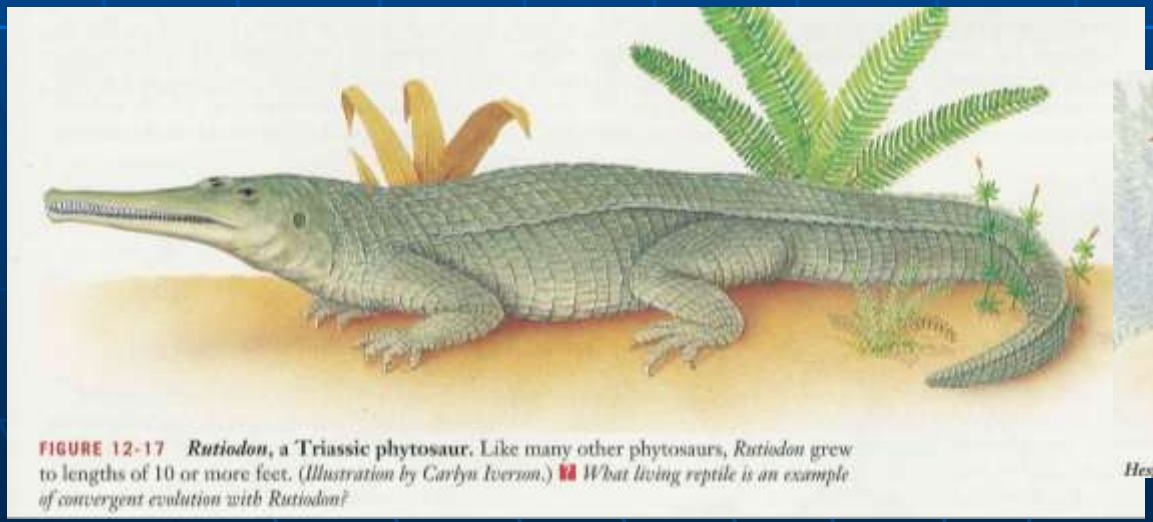
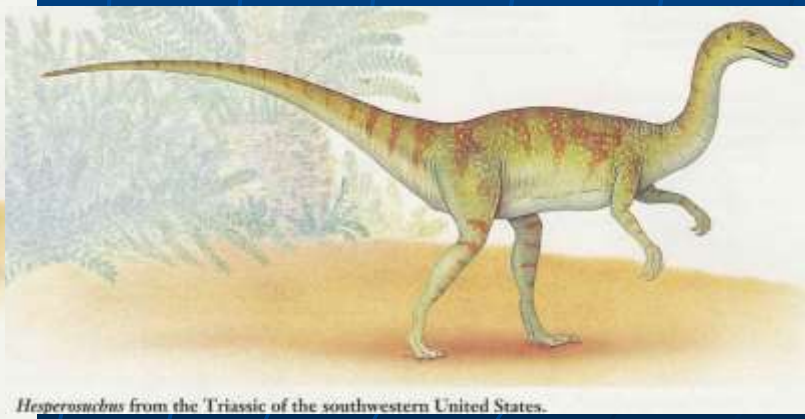
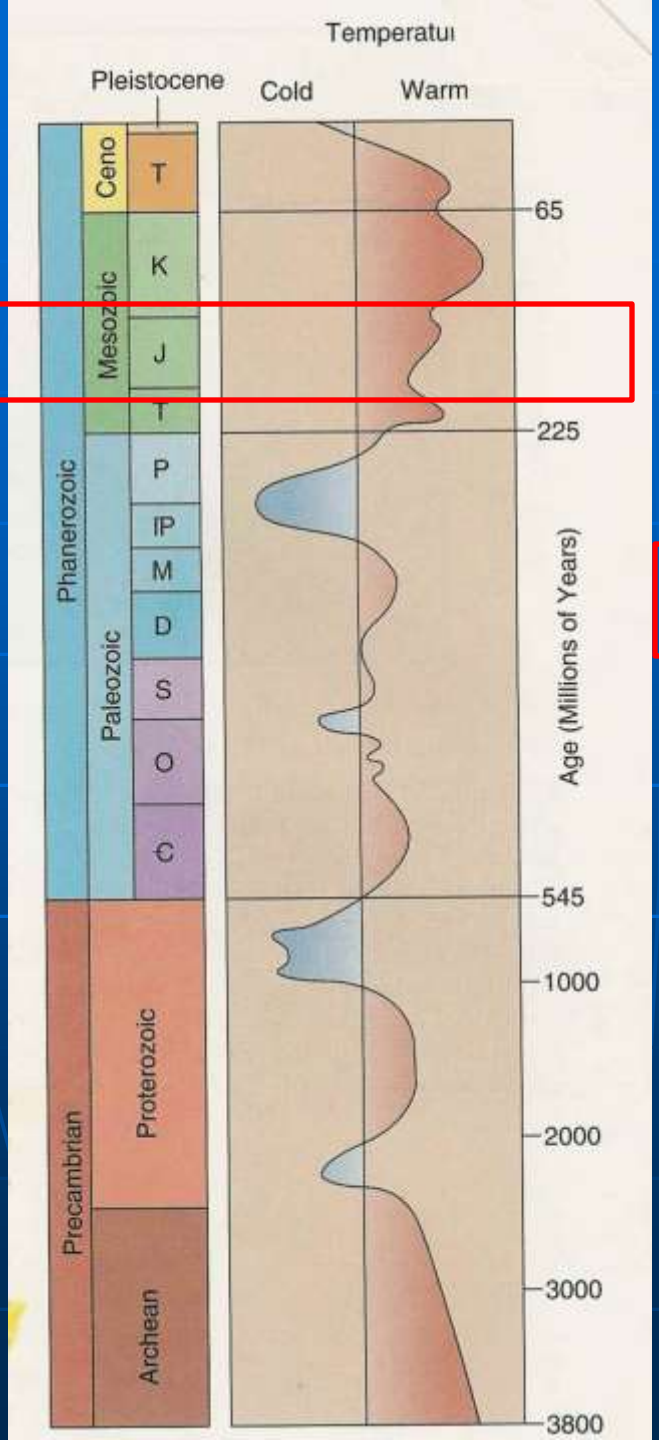


FIGURE 12-17 *Rutiodon*, a Triassic phytosaur. Like many other phytosaurs, *Rutiodon* grew to lengths of 10 or more feet. (*Illustration by Carlyn Iverson.*) ■ *What living reptile is an example of convergent evolution with Rutiodon?*



Hesperosuchus **from the Triassic of the southwestern United States.**

Temp. & Geologic Time Scale - Jurassic



EON	ERA	PERIOD		EPOCH		Ma
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					Early	1.8
		Tertiary	Neogene	Pliocene	Late	3.6
					Early	5.3
				Miocene	Late	11.2
					Middle	16.4
					Early	33.7
				Oligocene	Late	28.5
					Early	33.7
			Paleogene	Eocene	Late	41.3
					Middle	49.0
					Early	54.8
				Paleocene	Late	61.0
					Early	65.0
	Mesozoic	Cretaceous		Late		99.0
				Early		144
		Jurassic		Late		159
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		Triassic		Late		227
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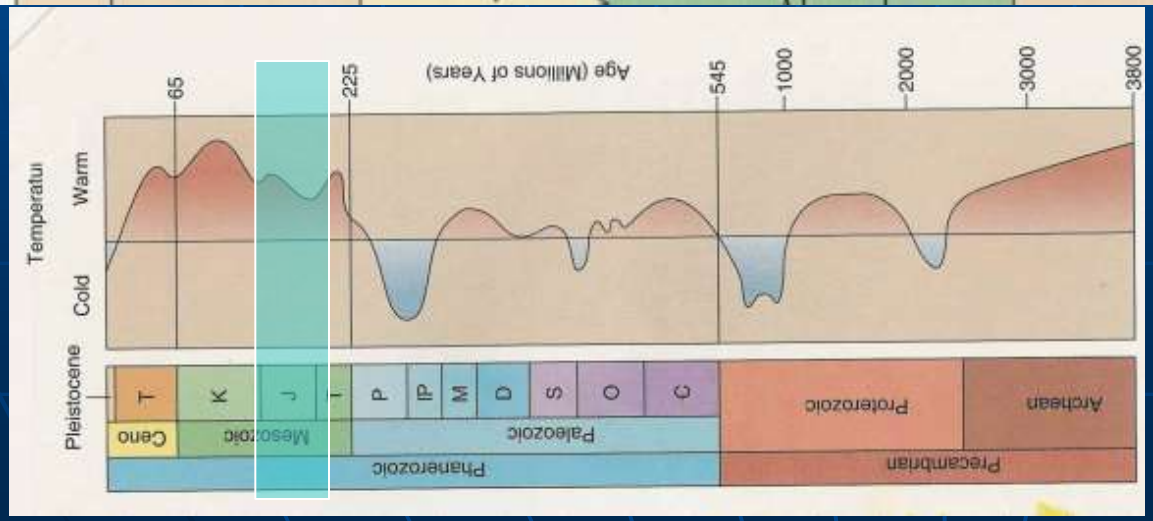
				Middle		391
				Early		417
		Silurian		Late		423
				Early		443
		Ordovician		Late		458
				Middle		470
				Early		490
		Cambrian		D		500
				C		512
				B		520
				A		543
zoic	Late					

Middle Mesozoic – Jurassic
Nevadan Orogeny (mountain building)

Geologic Time	Cratonic Sequences (Center of craton → Margin of craton)	Orogenic Events	Biologic Events	Ice Ages
CENOZOIC	Tejas	Himalayan Alpine	Age of mammals	
	65 m.y.a.	Laramide	*Massive extinctions*	
MESOZOIC – Cretaceous	Zuni	Sevier	First flowering plants Climax dinosaurs and ammonites	
		Nevadan		
MESOZOIC – Jurassic			First birds Abundant dinosaurs and ammonites	
MESOZOIC – Triassic			First dinosaurs First mammals Abundant cycads	
	250 m.y.a.	Sonoma	*Massive extinctions*	



Jurassic paleogeography

Jurassic sand seas – 190 Ma
Navajo Sandstone & correlatives

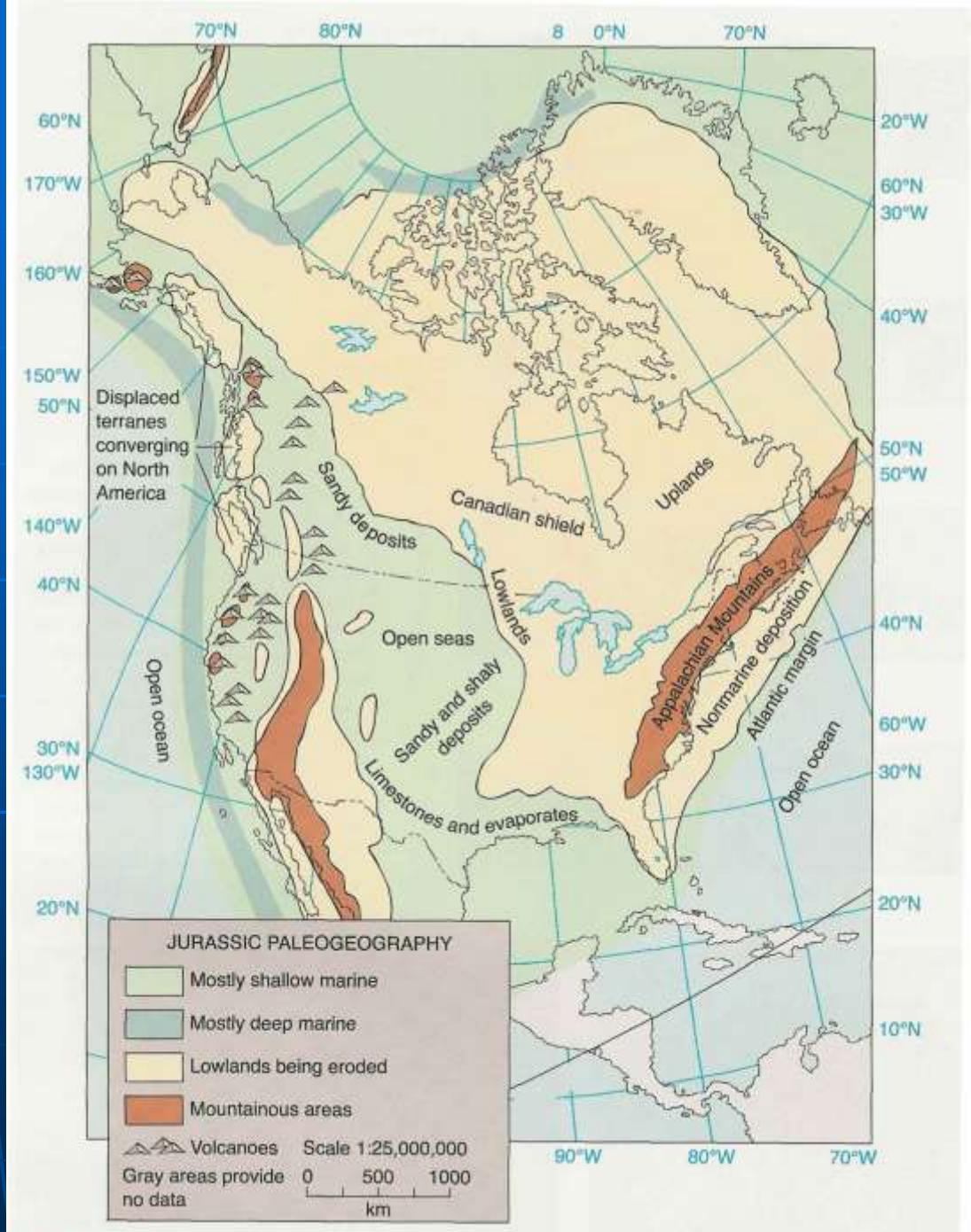
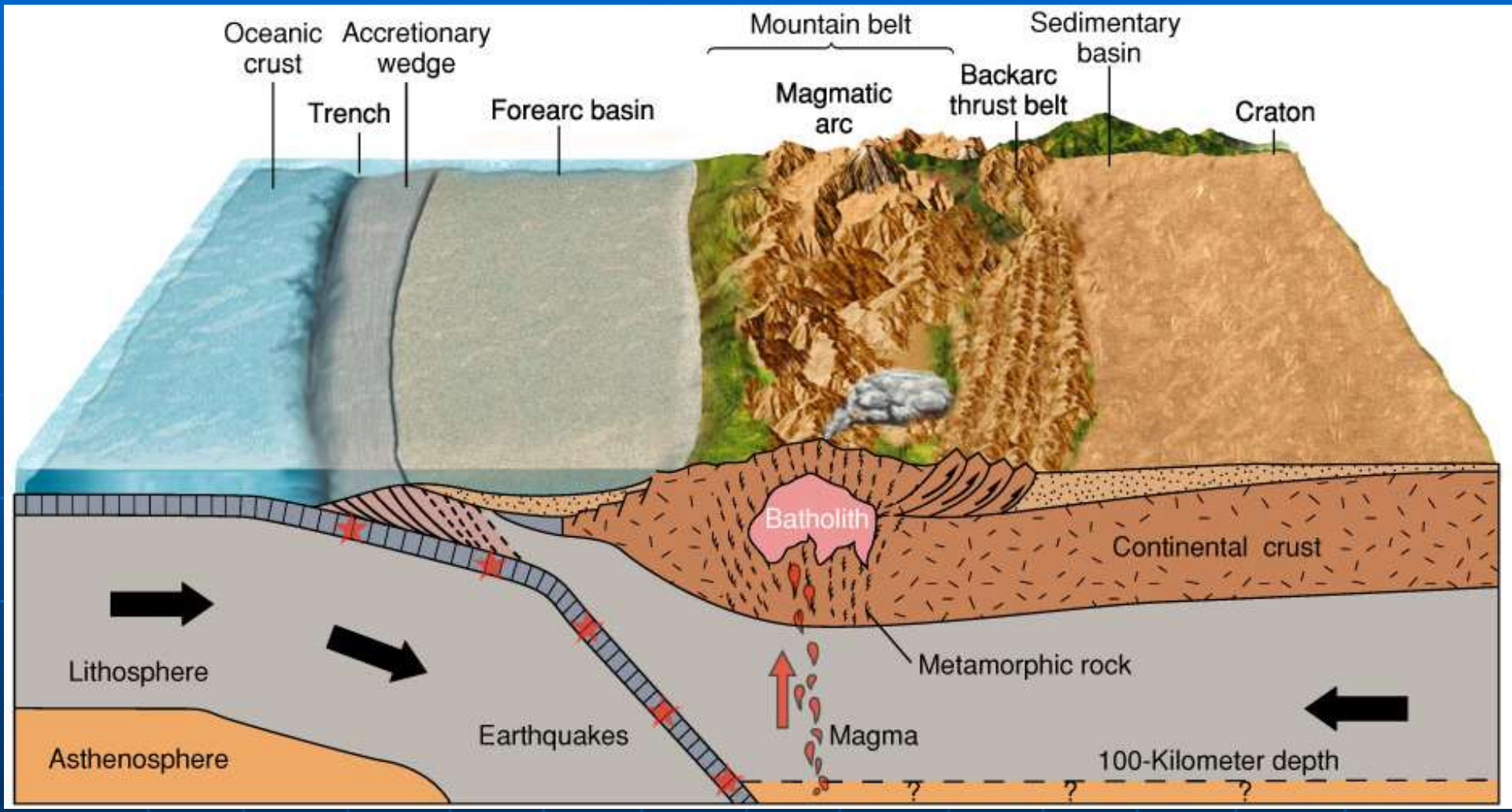


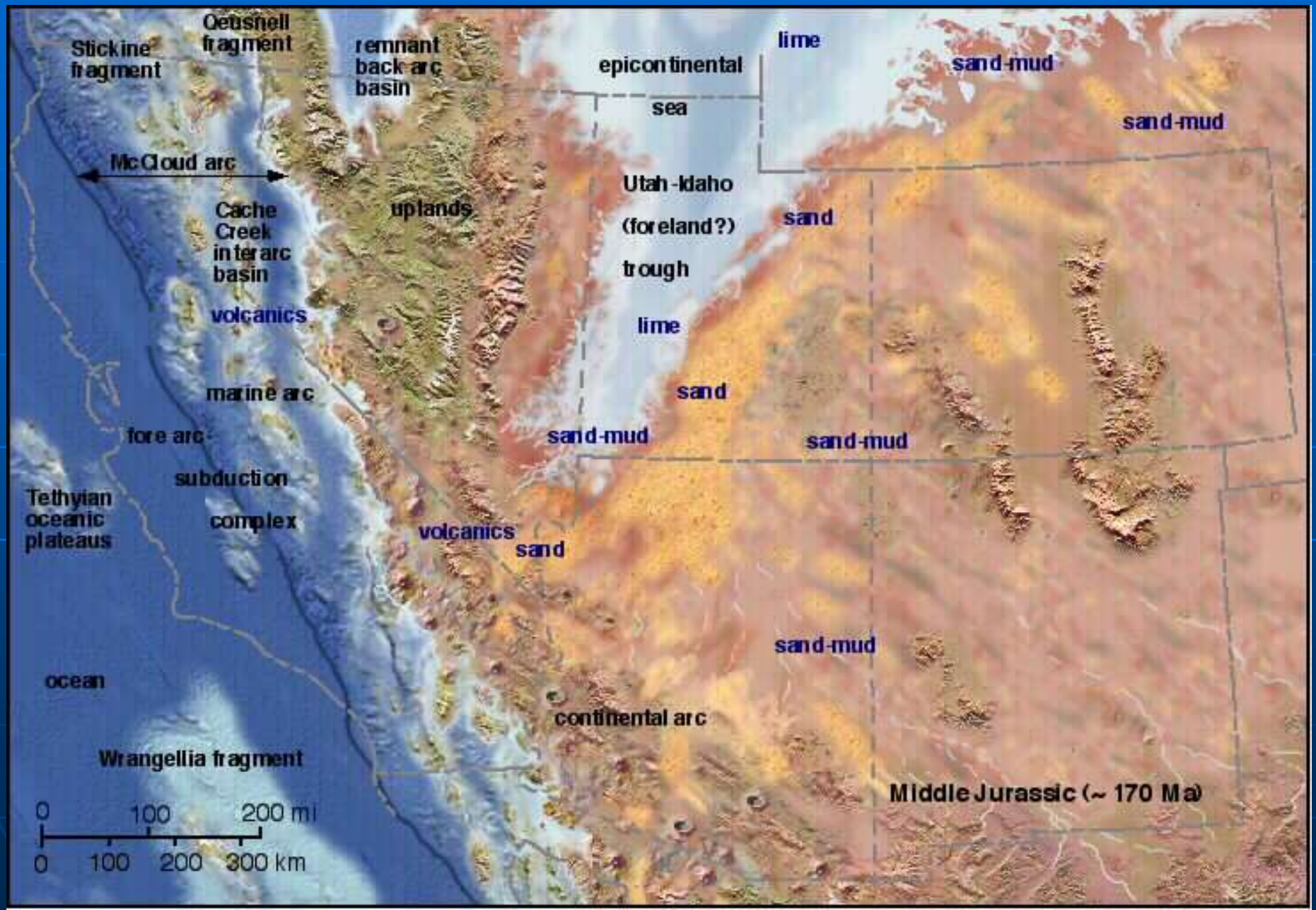
FIGURE 11–7 Generalized paleogeographic map for the Jurassic of North America.

Nevadan Orogeny (mtn. building)

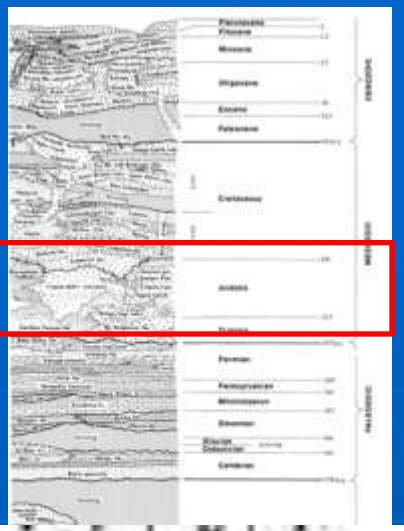


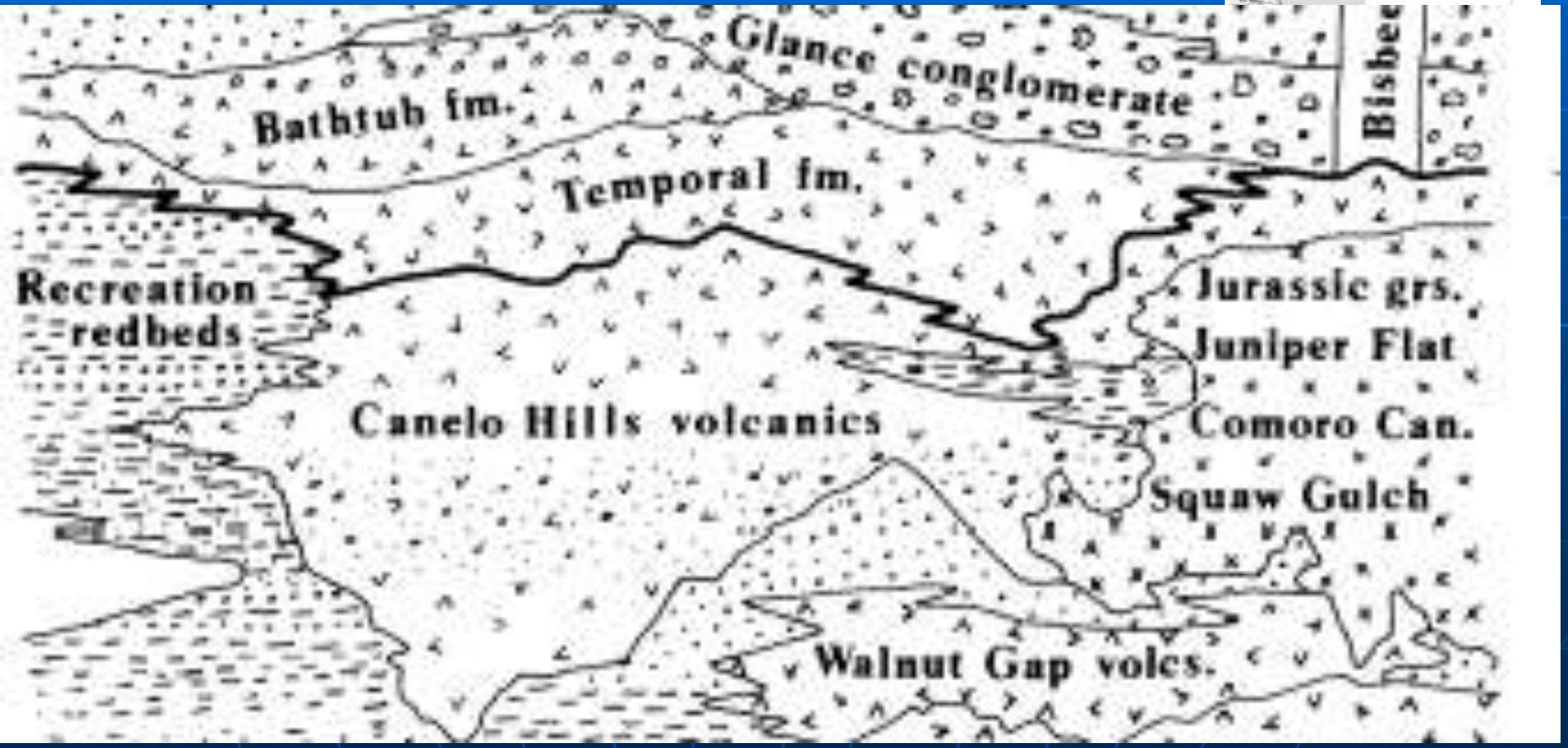
Jurassic granitic intrusions

Middle Jurassic



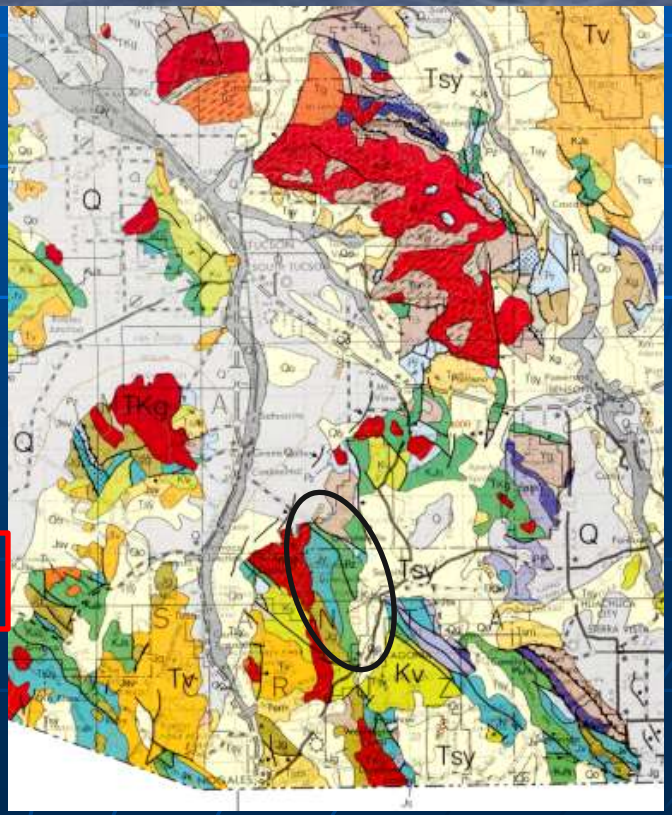
Jurassic Formations near Tucson



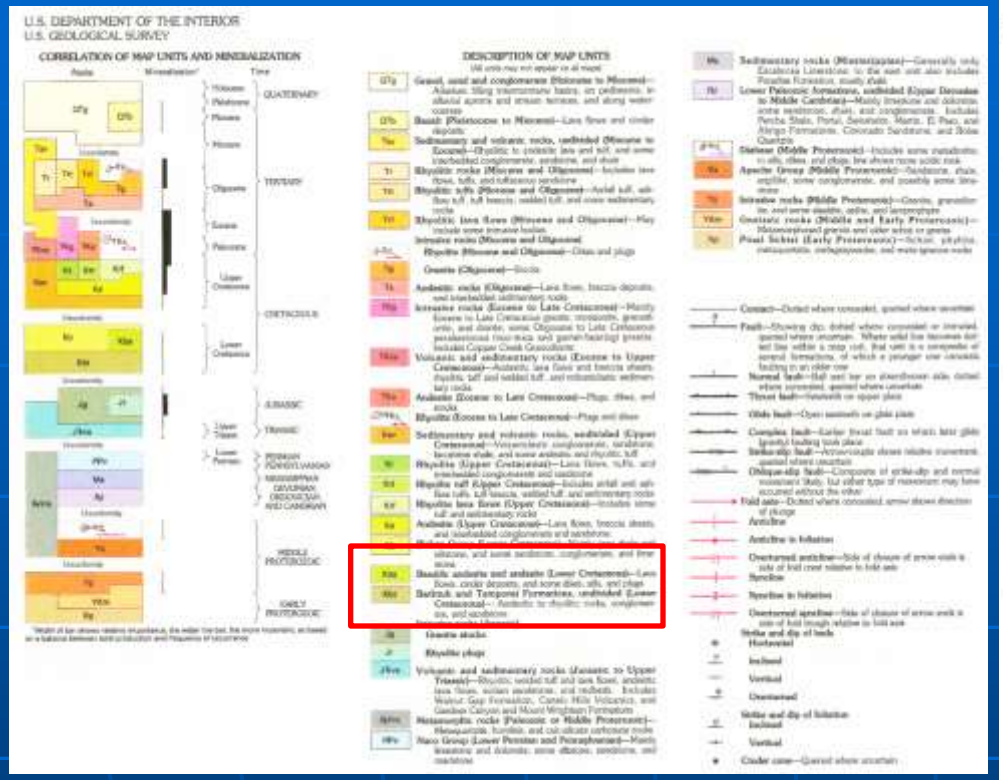


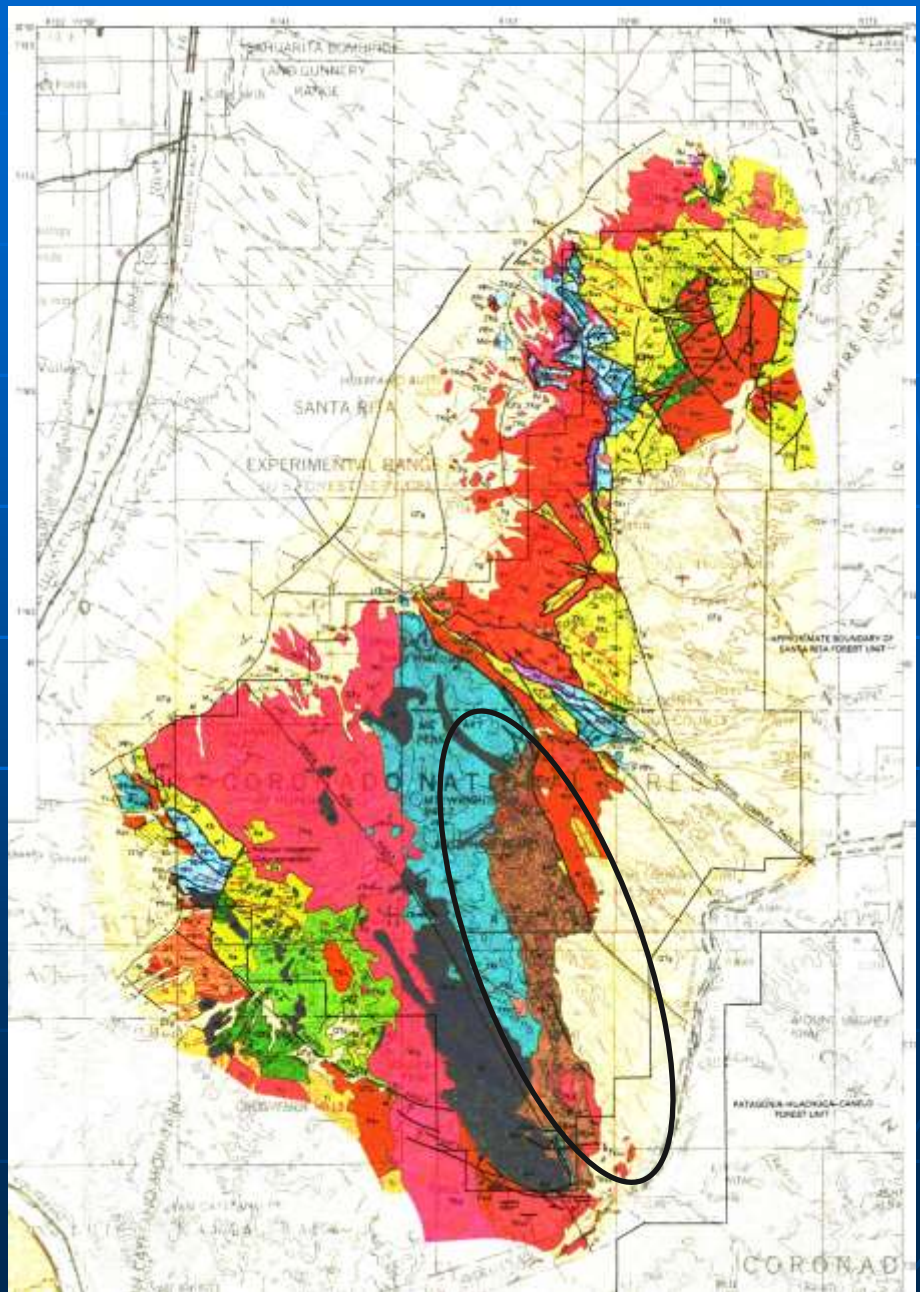
Middle Mesozoic – Jurassic (199.6-145.5 Ma) Santa Rita Mts.

Age	Group	Formation	Thickness (feet)	Subdivisions	Description
Paleocene(?)		Gringo Gulch Volcanics			Rhyolitic volcanics and clastic rocks.
		Unconformity (major intrusions)			
Late Cretaceous		Salero Formation	5,000±	Upper member	Sedimentary and volcanic rocks; 2,500± ft.
				Arkose member	Arkose and conglomerate largely facies of welded-tuff member; 500± ft.
				Welded-tuff member	Rhyodacite welded tuff; 1,200+ ft. 72.5± 2.2 m.y.
				Exotic-block member	Dacitic volcanics containing large exotic blocks; 1,000± ft.
				Lower member	Dacitic volcanics; 400+ ft.
		Unconformity			
		Fort Crittenden Formation	4,200–5,800+	Rhyolitic tuff member	Tuff intercalated in upper red conglomerate; 0–650 ft.
				Upper red conglomerate member.	Volcanic conglomerate to siltstone; 1,400+ ft.
				Brown conglomerate member.	Arkosic conglomerate to siltstone; 2,000+ ft.
				Lower red conglomerate member.	Volcanic conglomerate to siltstone; 800–1,200 ft.
				Shale member	Fossiliferous shale, and sandstone; 4–550+ ft.
		Unconformity			
Early Cretaceous	Bisbee Group (7,500+ ft)	Turney Ranch Formation	1,500+		Sandstone and red siltstone.
		Shellenberger Canyon Formation	1,600+		Siltstone and arkose.
		Apache Canyon Formation	1,500–2,000		Arkose, siltstone, and limestone lenses.
		Willow Canyon Formation	2,200+		Arkose and conglomerate.
		Glance Conglomerate	0–1,500+		Limestone-and-granite cobble conglomerate.
		Unconformity			
		Bathtub Formation	1,500–2,300	Upper member	Dacite volcanics and tuffaceous sandstone; 0–1,500 ft.
				Middle member	Rhyolite to andesite volcanics; 800–1,500 ft.
				Lower member	Conglomerate and volcanic sandstone; 700± ft.
		Minor unconformity			
		Temporal Formation	1,000–2,000	Upper member	Conglomerate and rhyolite volcanics; 600–1,000 ft.
				Middle member	Rhyolite to latite volcanics and conglomerate; 100–400 ft.
				Lower member	Rhyolitic to dacitic volcanics and conglomerate; 300–1,300 ft.
		Unconformity (major granite intrusion)			
Early Jurassic and Late Triassic		Canelo Hills(?) Volcanics	600+		Arkose, tuffaceous sandstone, tuff, and conglomerate. 173±7 m.y.
		Disconformity			
Triassic		Gardner Canyon Formation	1,000+	Mudstone member	Red sandstone, dacite volcanics and conglomerate. 192±20 m.y.
				Siltstone member	Red siltstone and chert pebble conglomerate.
		Unconformity			
		Mount Wrightson Formation	8,500±	Upper member	Eolian sandstone, andesitic to rhyodacitic volcanics; 2,000+ ft.
				Middle member	Rhyolitic to latitic volcanics, trace of clastic rocks; 5,000± ft. 220±30 m.y.
				Lower member	Dacitic to andesitic volcanics, and sandstone; 1,500+ ft.
		Inferred unconformity			
Permian		Rainvalley Formation			Marine limestone, dolomite, and sandstone.

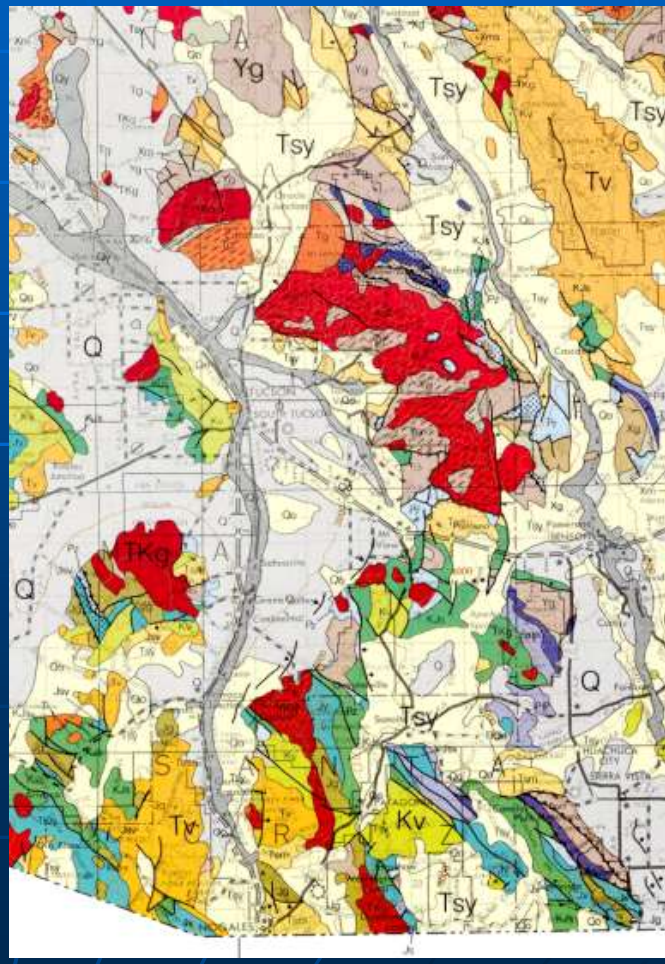


Jurassic – Santa Rita Mts.

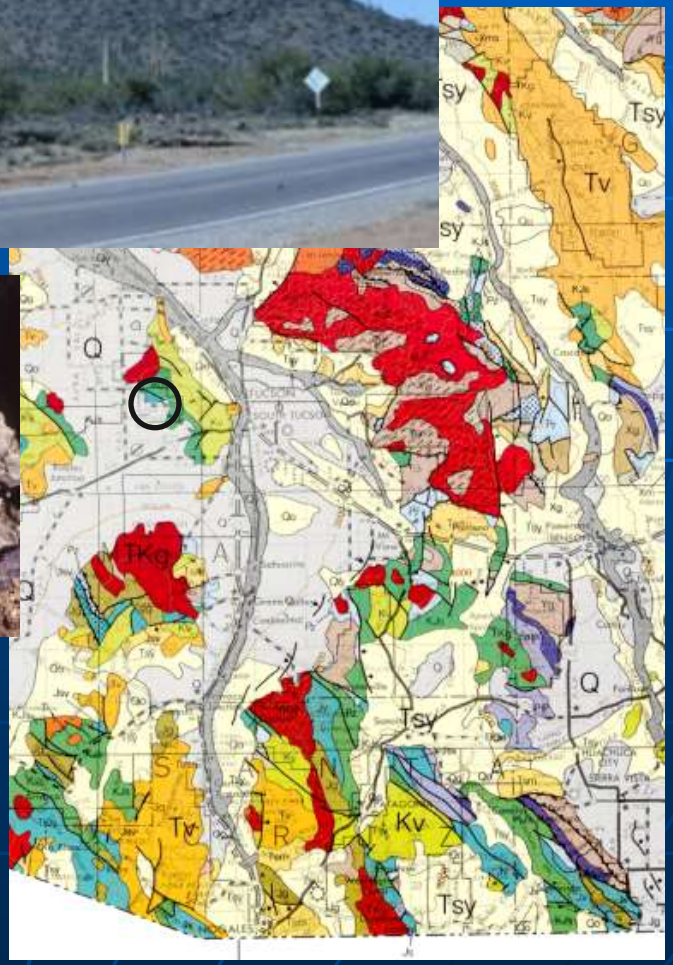




Middle Mesozoic – Jurassic
Catalina - Rincon Mts. - none



Middle Mesozoic – Jurassic
Tucson Mts. – Brown Mountain

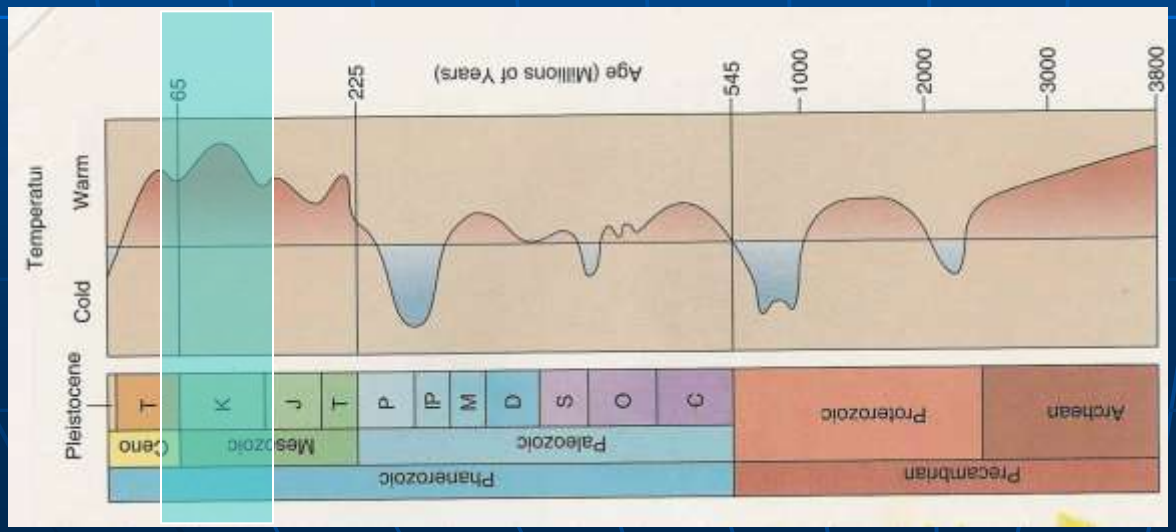


Jurassic – Bisbee copper-gold mine

Jurassic - Stegosaurus

Late Mesozoic – Cretaceous (145.5 – 65.5 Ma) Sevier & Laramide Orogenies (Mtn. Building)

Geologic Time		Cratonic Sequences: Center of craton	Cratonic Sequences: Margin of craton	Orogenic Events	Biologic Events	Ice Ages
CENOZOIC			Tejas	Himalayan Alpine	Age of mammals	
		65 m.y.a.		Laramide	*Massive extinctions*	
MESOZOIC	Cretaceous		Zuni	Sevier	First flowering plants Climax dinosaurs and ammonites	
				Nevadan	First birds	
	Jurassic				Abundant dinosaurs and ammonites	
					First dinosaurs	



Jurassic - Cretaceous batholiths

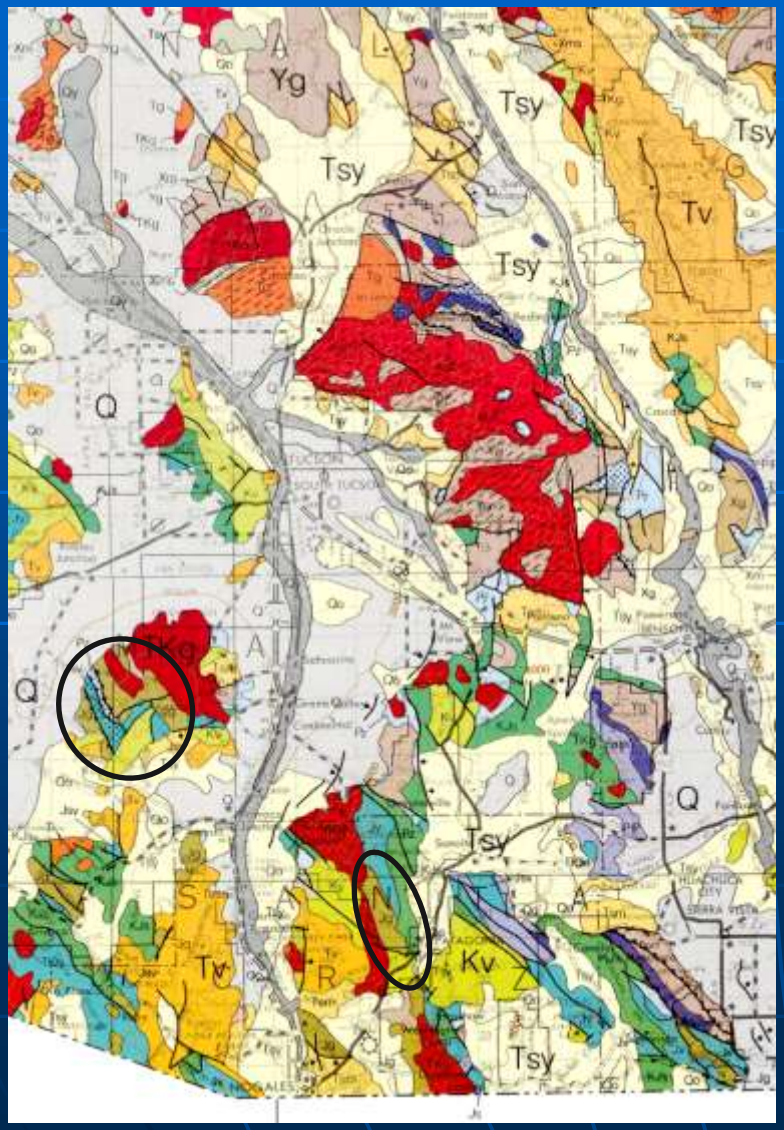
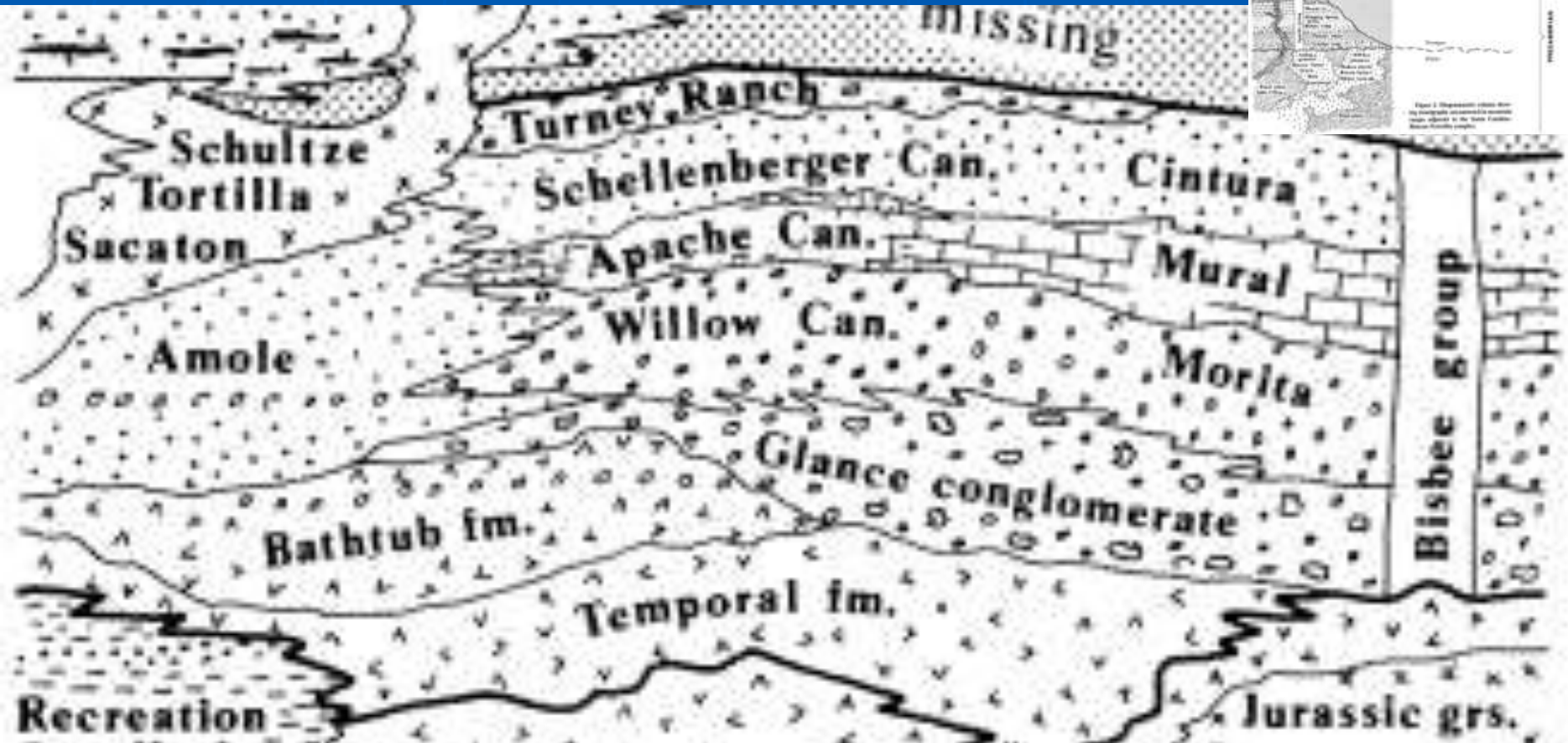


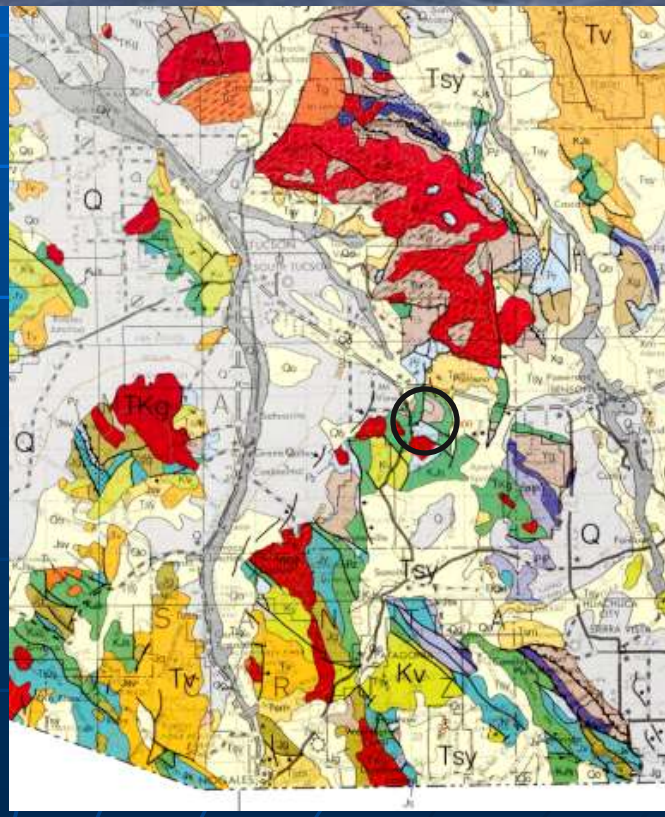
FIGURE 11-22 Mesozoic batholiths in west-central North America.

Early Cretaceous fms. near Tucson

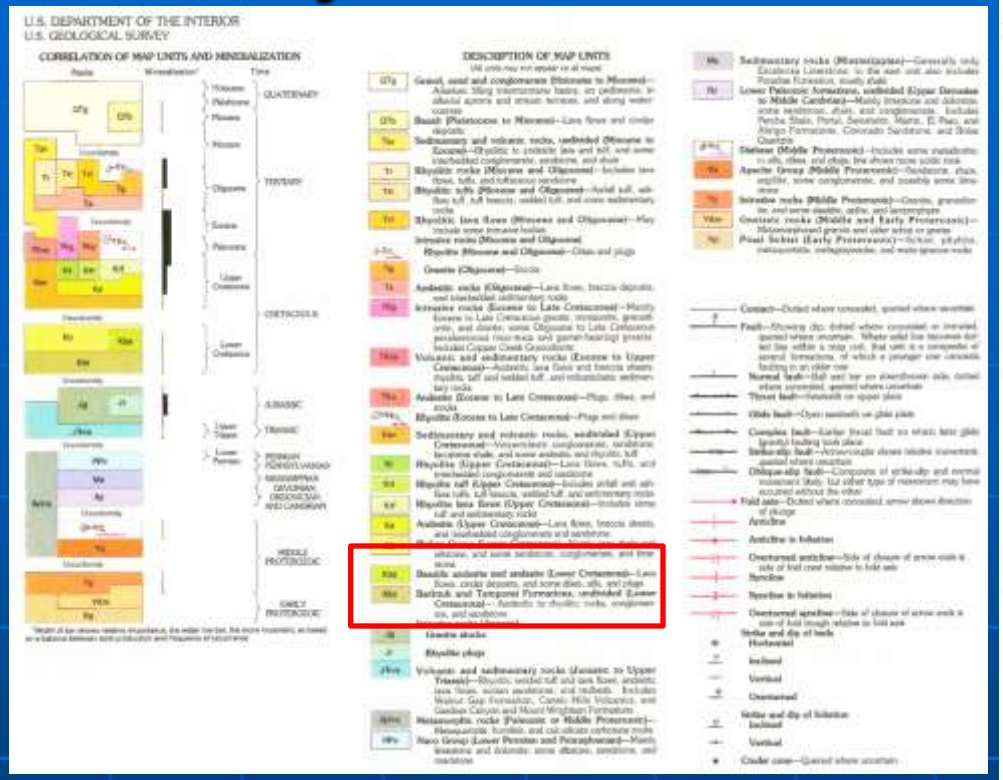


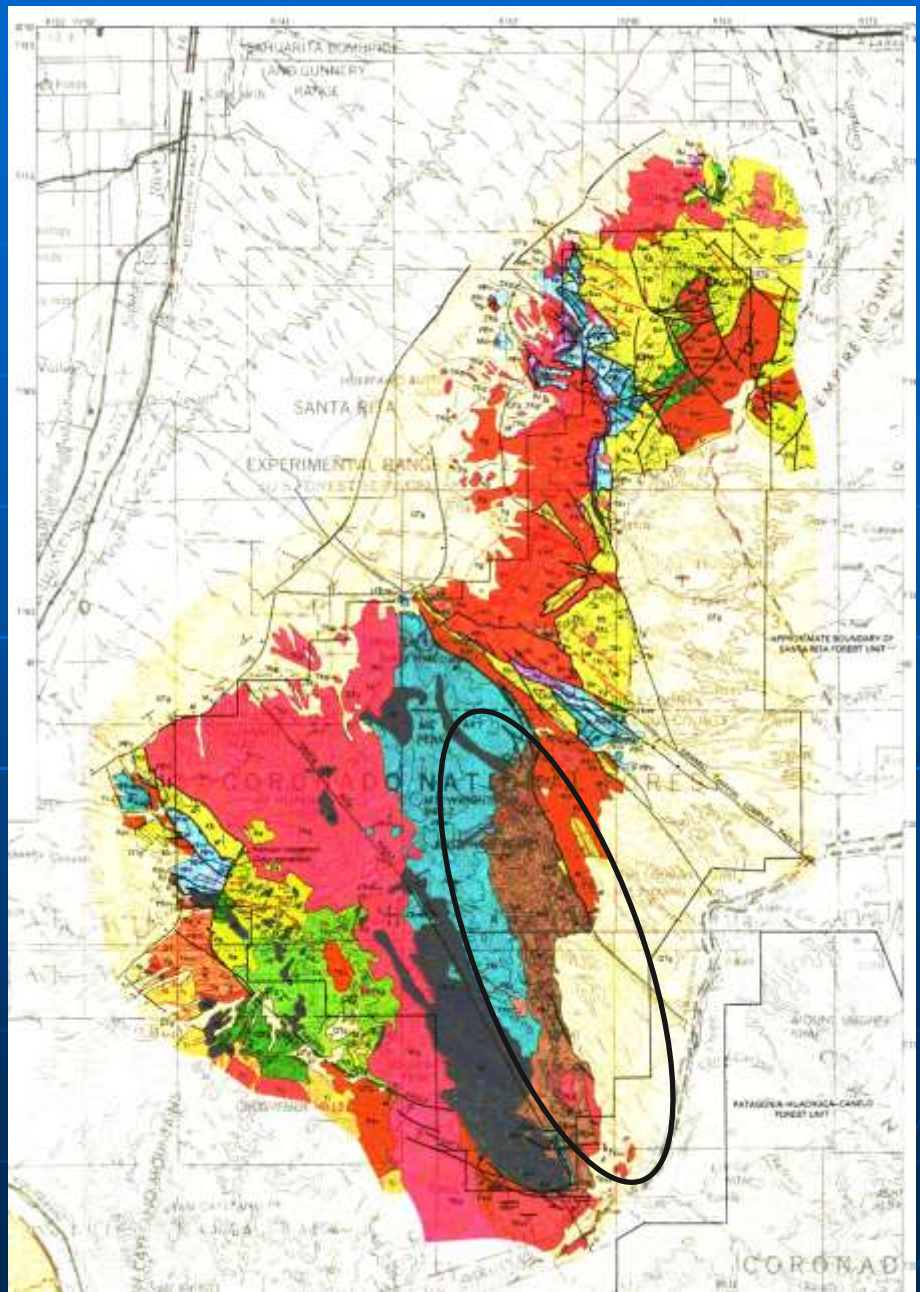
Late Mesozoic – Early Cretaceous (145.5 -65.5 Ma) Santa Rita Mts.

Age	Group	Formation	Thickness (feet)	Subdivisions	Description
Paleocene(?)		Gringo Gulch Volcanics			Rhyolitic volcanics and clastic rocks.
		Unconformity (major intrusions)			
Late Cretaceous		Salero Formation	5,000±	Upper member	Sedimentary and volcanic rocks; 2,500± ft.
				Arkose member	Arkose and conglomerate largely facies of welded-tuff member; 500± ft.
				Welded-tuff member	Rhyodacite welded tuff; 1,200+ ft. 72.5± 2.2 m.y.
				Exotic-block member	Dacitic volcanics containing large exotic blocks; 1,000± ft.
				Lower member	Dacitic volcanics; 400+ ft.
		Unconformity			
		Fort Crittenden Formation	4,200–5,800+	Rhyolitic tuff member	Tuff intercalated in upper red conglomerate; 0–650 ft.
				Upper red conglomerate member.	Volcanic conglomerate to siltstone; 1,400+ ft.
				Brown conglomerate member.	Arkosic conglomerate to siltstone; 2,000+ ft.
				Lower red conglomerate member.	Volcanic conglomerate to siltstone; 800–1,200 ft.
				Shale member	Fossiliferous shale, and sandstone; 4–550+ ft.
		Unconformity			
Early Cretaceous	Bisbee Group (7,500+ ft)	Turney Ranch Formation	1,500+		Sandstone and red siltstone.
		Shellenberger Canyon Formation	1,600+		Siltstone and arkose.
		Apache Canyon Formation	1,500–2,000		Arkose, siltstone, and limestone lenses.
		Willow Canyon Formation	2,200+		Arkose and conglomerate.
		Glance Conglomerate	0–1,500+		Limestone-and-granite cobble conglomerate.
		Unconformity			
		Bathtub Formation	1,500–2,300	Upper member	Dacite volcanics and tuffaceous sandstone; 0–1,500 ft.
				Middle member	Rhyolite to andesite volcanics; 800–1,500 ft.
				Lower member	Conglomerate and volcanic sandstone; 700± ft.
		Minor unconformity			
		Temporal Formation	1,000–2,000	Upper member	Conglomerate and rhyolite volcanics; 600–1,000 ft.
				Middle member	Rhyolite to latite volcanics and conglomerate; 100–400 ft.
				Lower member	Rhyolitic to dacitic volcanics and fanglomerate; 200–1,300 ft.
		Unconformity (major granite intrusion)			
Early Jurassic and Late Triassic		Canelo Hills(?) Volcanics	600+		Arkose, tuffaceous sandstone, tuff, and conglomerate. 173±7 m.y.
		Disconformity			
Triassic		Gardner Canyon Formation	1,000+	Mudstone member	Red mudstone, dacite volcanics and conglomerate. 192±20 m.y.
				Siltstone member	Red siltstone and chert pebble conglomerate.
		Unconformity			
		Mount Wrightson Formation	8,500±	Upper member	Eolian sandstone, andesitic to rhyodacitic volcanics; 2,000+ ft.
				Middle member	Rhyolitic to latitic volcanics, trace of clastic rocks; 5,000+ ft. 220±30 m.y.
				Lower member	Dacitic to andesitic volcanics, and sandstone; 1,500+ ft.
		Inferred unconformity			
Permian		Rainvalley Formation			Marine limestone, dolomite, and sandstone.



Early Cretaceous – Santa Rita Mts.

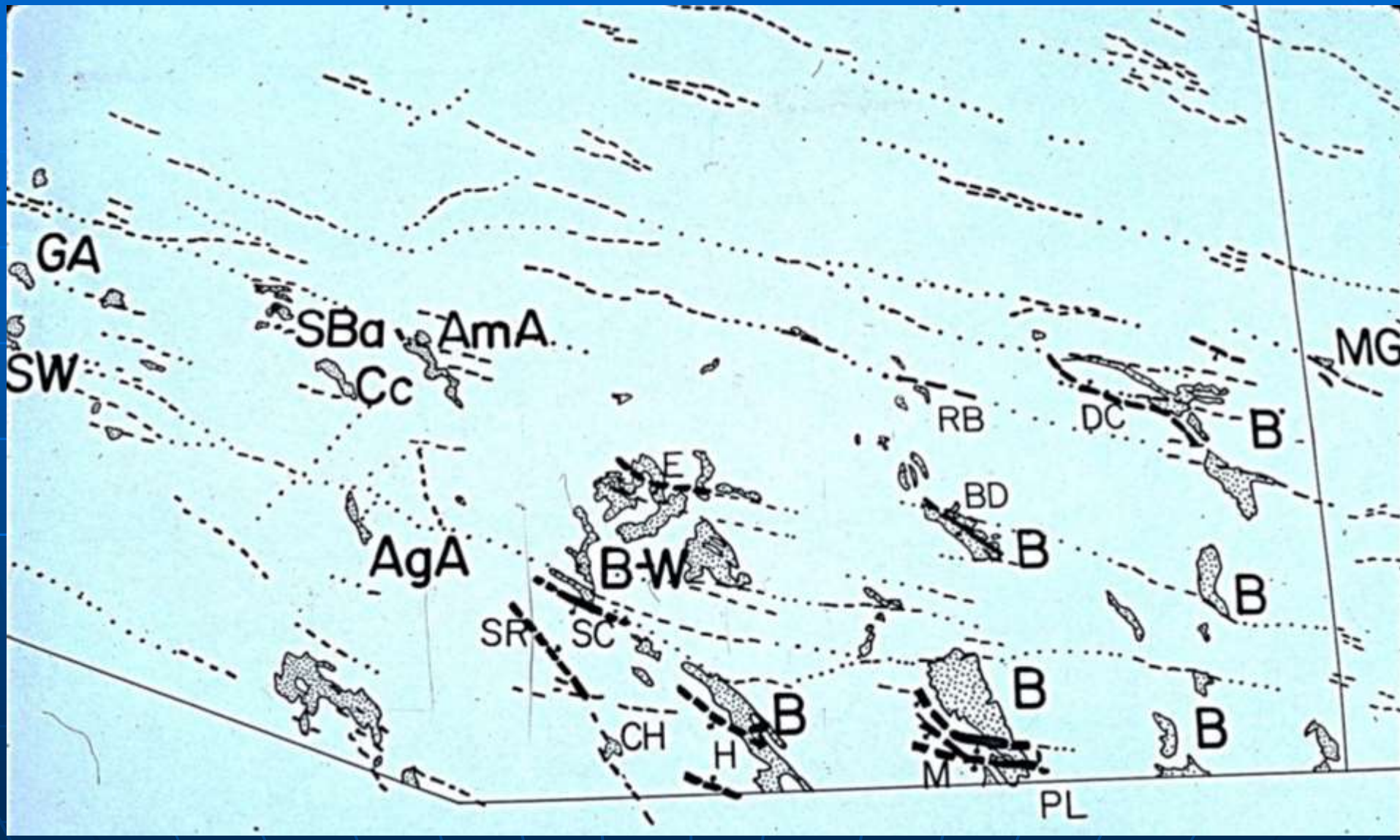




Bathtub Fm. Volcanics

Temporal Fm. Rhyolite
Volcanics and conglomerates)

Bisbee fault-block basins



Cretaceous paleogeography

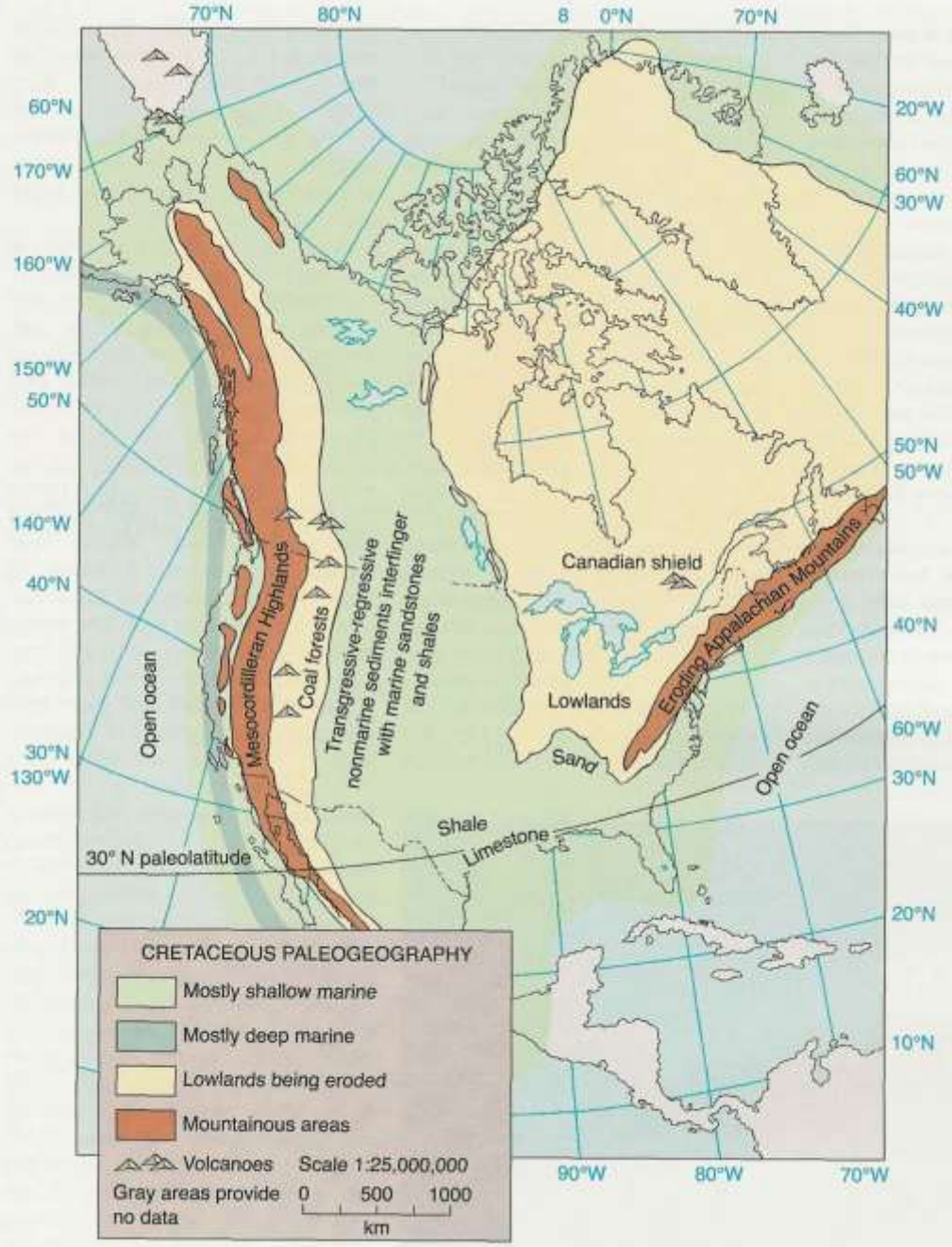
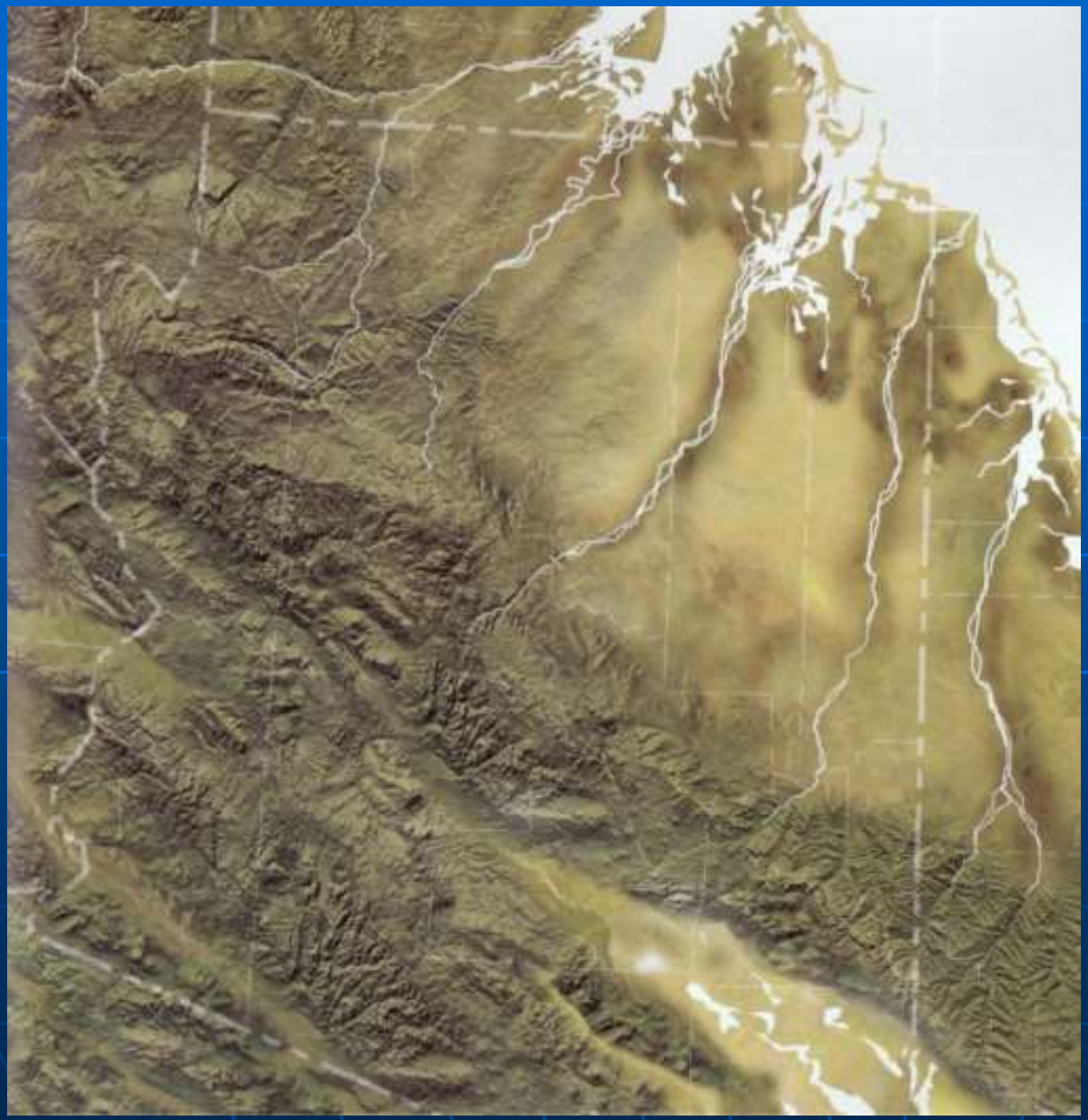


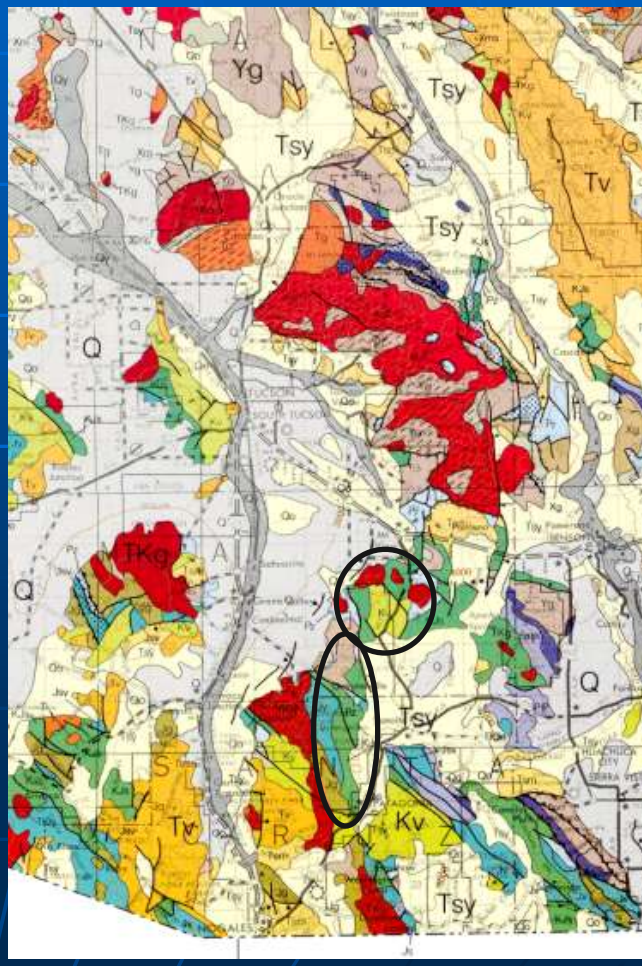
FIGURE 11-12 Generalized paleogeographic map for the Cretaceous of North America.

Early Cretaceous - 100 Ma - seaway

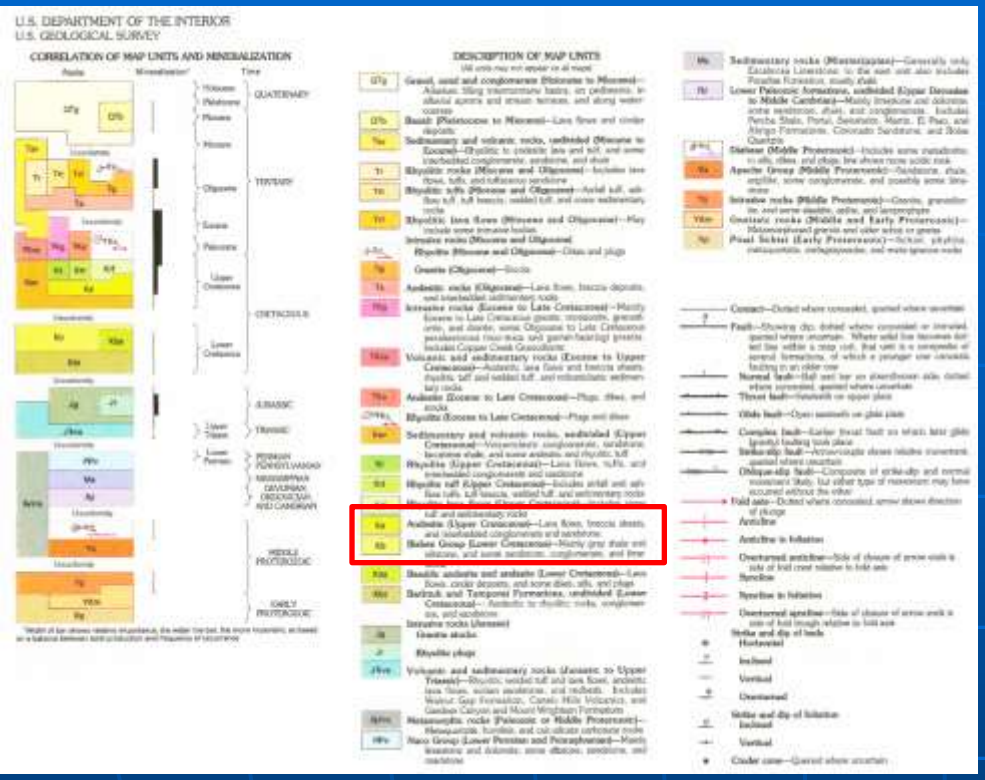


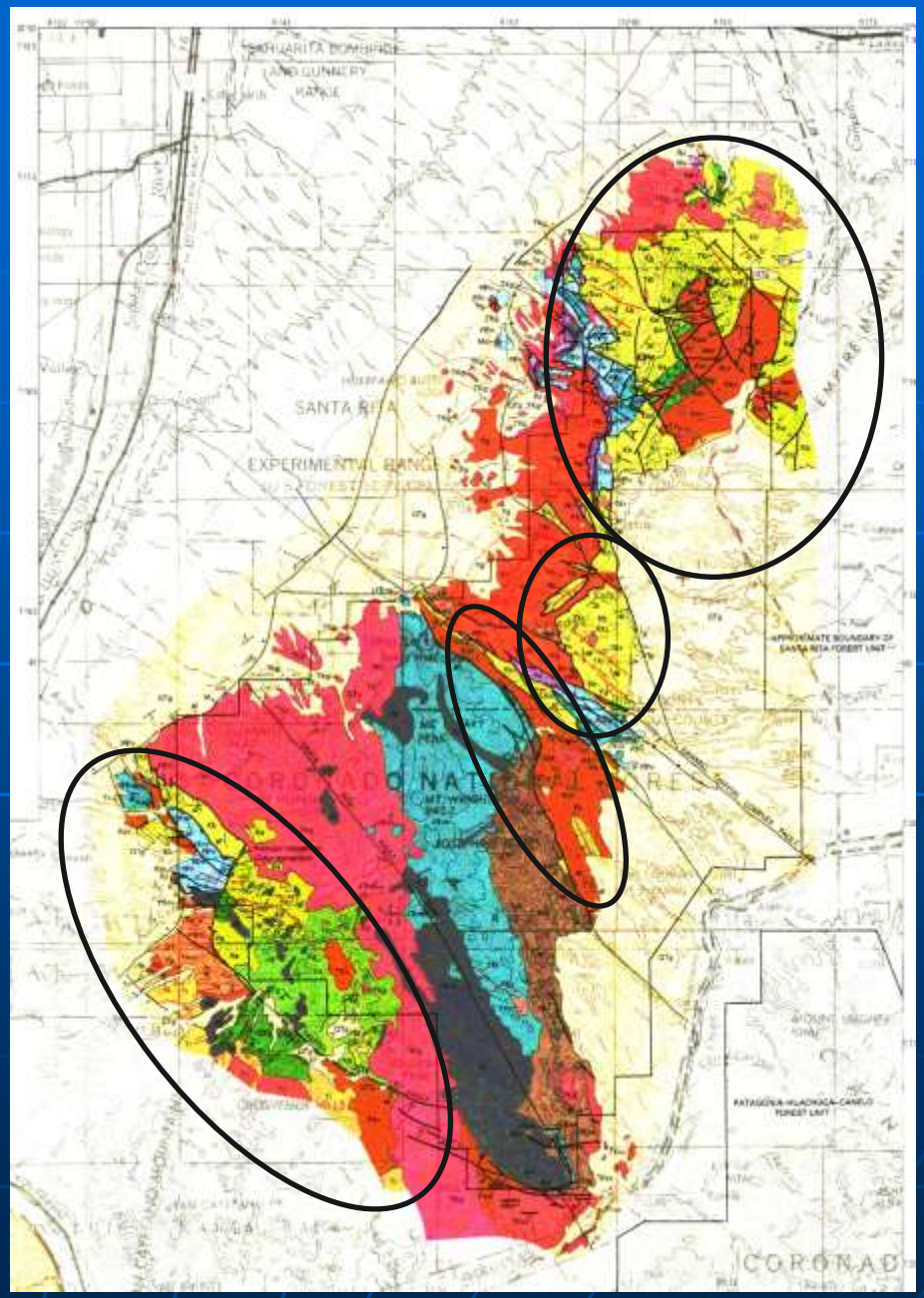
Late Mesozoic – later Early Cretaceous (~100 Ma) Santa Rita Mts. Bisbee Group

Age	Group	Formation	Thickness (feet)	Subdivisions	Description
Paleocene(?)		Gringo Gulch Volcanics			Rhyolitic volcanics and clastic rocks.
		Unconformity (major intrusions)			
Late Cretaceous		Salero Formation	5,000±	Upper member	Sedimentary and volcanic rocks; 2,500± ft.
				Arkose member	Arkose and conglomerate largely facies of welded-tuff member; 500± ft.
				Welded-tuff member	Rhyodacite welded tuff; 1,200+ ft. 72.5± 2.2 m.y.
				Exotic-block member	Dacitic volcanics containing large exotic blocks; 1,000± ft.
				Lower member	Dacitic volcanics; 400+ ft.
		Unconformity			
		Fort Crittenden Formation	4,200–5,800+	Rhyolitic tuff member	Tuff intercalated in upper red conglomerate; 0–650 ft.
				Upper red conglomerate member.	Volcanic conglomerate to siltstone; 1,400+ ft.
				Brown conglomerate member.	Arkosic conglomerate to siltstone; 2,000+ ft.
				Lower red conglomerate member.	Volcanic conglomerate to siltstone; 800–1,200 ft.
				Shale member	Fossiliferous shale, and sandstone; 4–550+ ft.
		Unconformity			
Early Cretaceous	Bisbee Group (7,500+ ft)	Turney Ranch Formation	1,500+		Sandstone and red siltstone.
		Shellenberger Canyon Formation	1,600+		Siltstone and arkose.
		Apache Canyon Formation	1,500–2,000		Arkose, siltstone, and limestone lenses.
		Willow Canyon Formation	2,200+		Arkose and conglomerate.
		Glance Conglomerate	0–1,500+		Limestone-and-granite cobble conglomerate.
		Unconformity			
		Bathtub Formation	1,500–2,300	Upper member	Dacite volcanics and tuffaceous sandstone; 0–1,500 ft.
				Middle member	Rhyolite to andesite volcanics; 800–1,000 ft.
				Lower member	Conglomerate and volcanic sandstone; 700± ft.
		Minor unconformity			
		Temporal Formation	1,000–2,000	Upper member	Conglomerate and rhyolite volcanics; 600–1,000 ft.
				Middle member	Rhyolite to latite volcanics and conglomerate; 100–400 ft.
				Lower member	Rhyolitic to dacitic volcanics and fanglomerate; 200–1,300 ft.
		Unconformity (major granite intrusion)			
Early Jurassic and Late Triassic		Canelo Hills(?) Volcanics	600+		Arkose, tuffaceous sandstone, tuff, and conglomerate. 173±7 m.y.
		Disconformity			
Triassic		Gardner Canyon Formation	1,000+	Mudstone member	Red mudstone, dacite volcanics and conglomerate. 192±20 m.y.
				Siltstone member	Red siltstone and chert pebble conglomerate.
		Unconformity			
		Mount Wrightson Formation	8,500±	Upper member	Eolian sandstone, andesitic to rhyodacitic volcanics; 2,000+ ft.
				Middle member	Rhyolitic to latitic volcanics, trace of clastic rocks; 5,000± ft. 220±30 m.y.
				Lower member	Dacitic to andesitic volcanics, and sandstone; 1,500+ ft.
		Inferred unconformity			
Permian		Rainvalley Formation			Marine limestone, dolomite, and sandstone.



Cretaceous sediments – Santa Rita Mts.

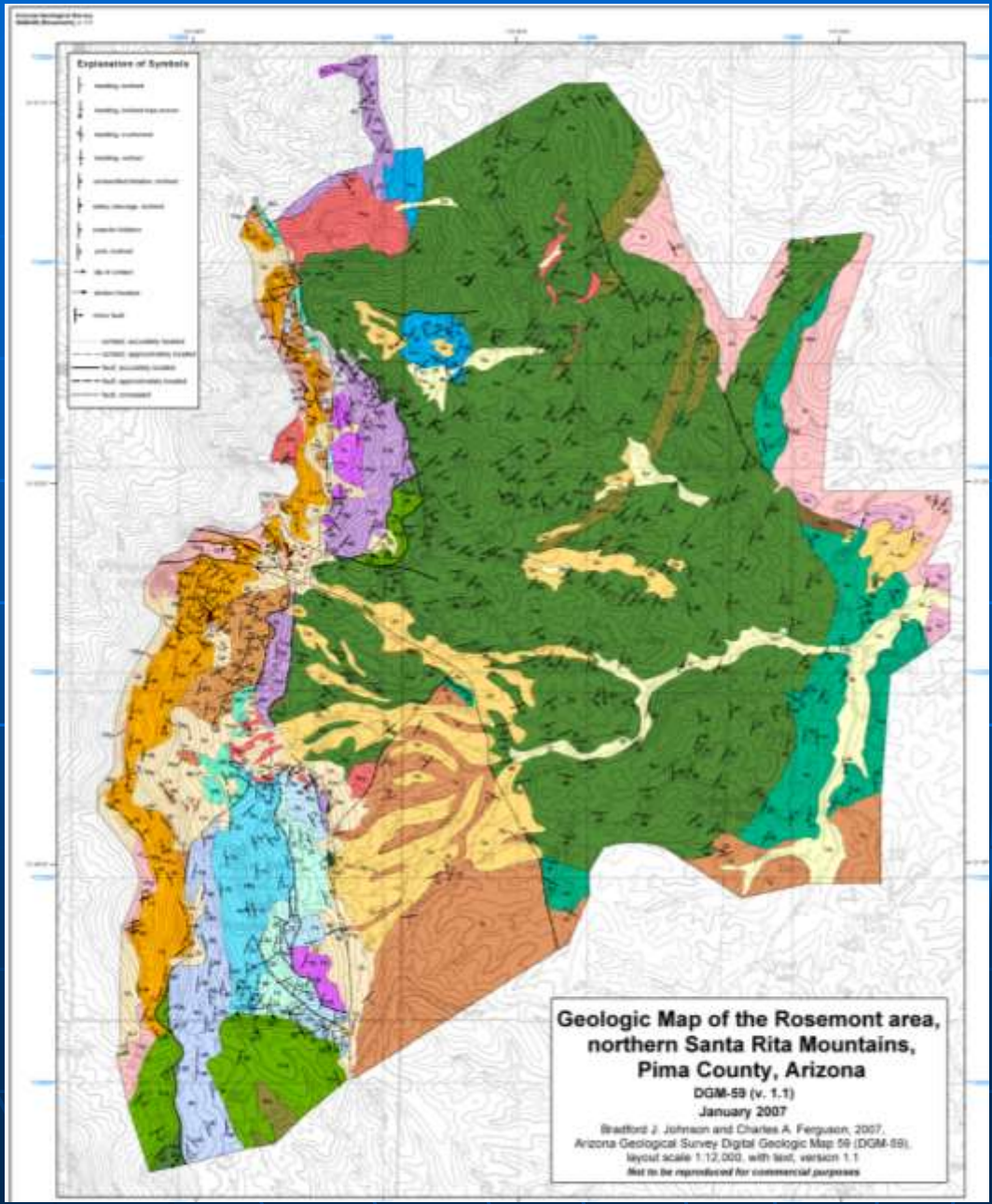




Bisbee Group – pale yellow green – Kb – 100 Ma – gray shale and siltstone and some sandstone, conglomerate, and limestone

Source: Drewes, 1996, USGS Bull. 2083, plate 4

Geologic Map of Rosemont area



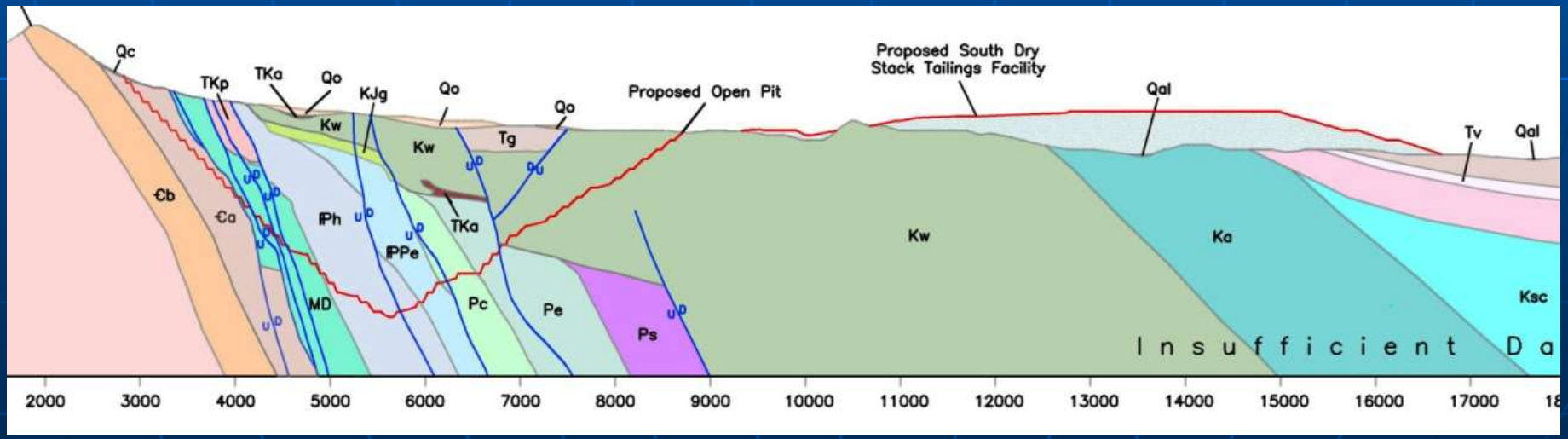
- Near vertical Paleozoic (blue) Limestones near crest
- Fault-bounded Paleozoics on west
- Mineralized Paleozoics buried under Cretaceous and Tertiary sedimentary rocks
- Cretaceous (green) bedding trends northeast

Early Cretaceous – Willow Canyon Fm.

- Lower Bisbee Group
- Siltstone & mudstone
- Alluvial – deltaic deposits

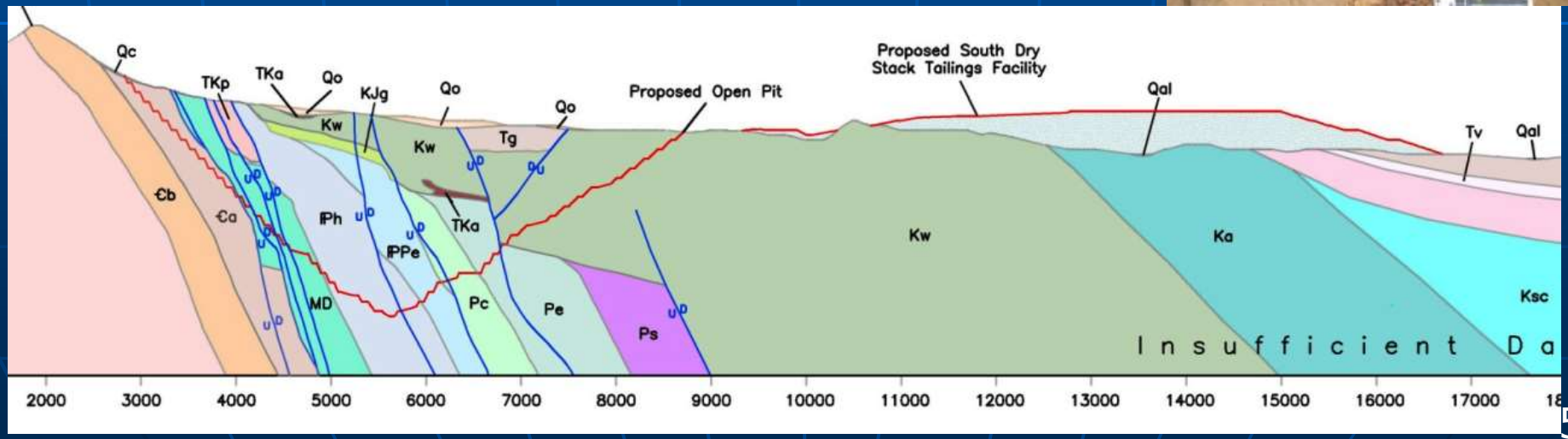
Arizona – land area

Willow Canyon thin-bedded siltstone – delta deposits

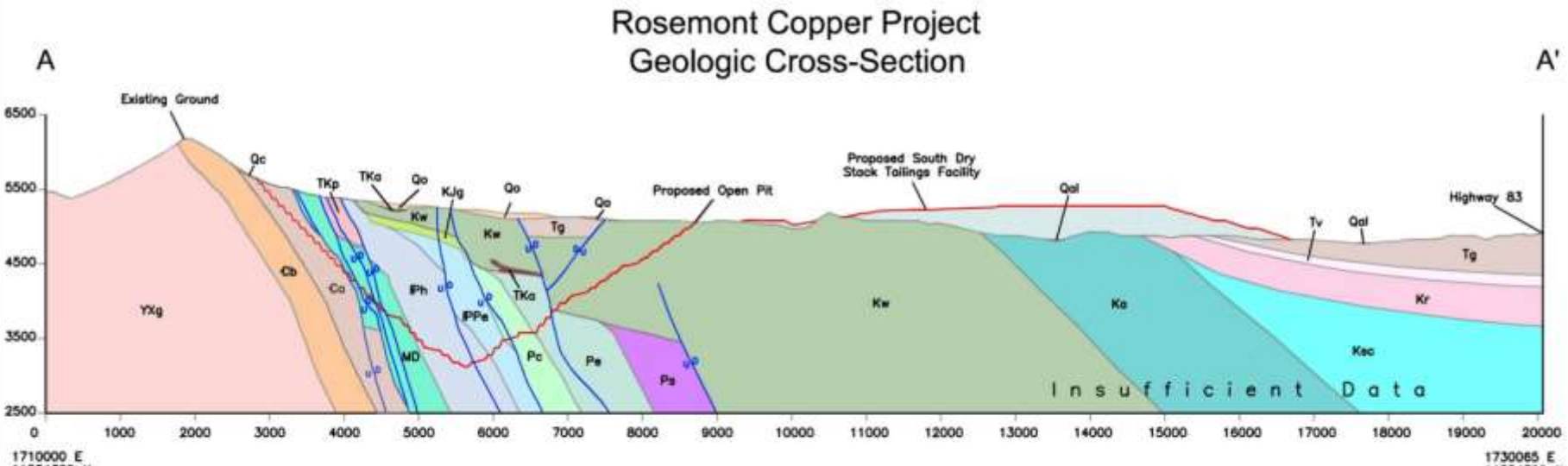


Early Cretaceous – Apache Canyon Fm.

- Overlies Willow Canyon Fm.
- Green Ka on cross section
- Siltstone, mudstone, some fine grained sandstone & arkose, some thin bedded brackish water limestone
- Correlates in time with Mural Limestone, but terrestrial – rivers, deltas



Cross section of Rosemont area



CROSS-SECTION A-A'

Hd	DISTURBED AREAS (HOLOCENE)
Qa	YOUNGER ALLUVIUM (HOLOCENE – LATE PLEISTOCENE)
Qc	COLLUVIUM AND TALUS (HOLOCENE – LATE PLEISTOCENE)
Qo	OLDER ALLUVIUM (LATE PLEISTOCENE)
Tg	GILA CONGLOMERATE (PLIOCENE – MIOCENE)
Tv	EXTRUSIVE RHYOLITE AND RHYODACITE (MIOCENE – LATE OLIGOCENE)
Tc	CONGLOMERATE (MIOCENE – EOCENE)
TKg	GRANODIORITE AND QUARTZ MONZONITE STOCKS (PALEOGENE – LATE CRETACEOUS)
s	SKARN (PALEOGENE – LATE CRETACEOUS)
TKp	QUARTZ–FELDSPAR PORPHYRY (PALEOGENE – LATE CRETACEOUS)
TKa	ANDESITE PORPHYRY (PALEOGENE – LATE CRETACEOUS)
Kr	MOUNT FAGAN RHYOLITE, INCLUDING MEGABRECCIA AND RELATED SEDIMENTS (LATE CRETACEOUS)
Ksc	SHELLENBERGER CANYON FORMATION, BISBEE GROUP (EARLY CRETACEOUS)
Ka	APACHE CANYON FORMATION, BISBEE GROUP (EARLY CRETACEOUS)
Kw	WILLOW CANYON FORMATION, BISBEE GROUP (EARLY CRETACEOUS)
Km	MAFIC LAVA, BISBEE GROUP (EARLY CRETACEOUS)
KJg	GLANCE CONGLOMERATE, BISBEE GROUP (LATE JURASSIC AND/OR EARLY CRETACEOUS)
KJl	GLANCE CONGLOMERATE CLASTIC DIKE, BISBEE GROUP (LATE JURASSIC AND/OR EARLY CRETACEOUS)
Prv	RAIN VALLEY FORMATION, NACO GROUP (PERMIAN)
Pch	CONCHA LIMESTONE, NACO GROUP (PERMIAN)
Pq	QUARTZ SANDSTONE, NACO GROUP (PERMIAN)
Psu	UPPER SHERRER FORMATION, NACO GROUP (PERMIAN)
Ps	SHERRER FORMATION, NACO GROUP (PERMIAN)
Pe	EPITAPH FORMATION, NACO GROUP (PERMIAN)
Pc	COLINA LIMESTONE, NACO GROUP (PERMIAN)
IPPe	EARP FORMATION, NACO GROUP (PERMIAN – PENNSYLVANIAN)
IPh	HORQUILLA LIMESTONE, NACO GROUP (PENNSYLVANIAN)
MD	ESCABROSA LIMESTONE, MARTIN FORMATION, UNDIFFERENTIATED (MISSISSIPIAN – DEVONIAN)
Ꞓa	ABRIGO FORMATION (CAMBRIAN)
Ꞓb	BOLSA QUARTZITE (CAMBRIAN)
YXg	QUARTZ MONZONITE (EARLY OR MIDDLE PROTEROZOIC)

GEOLOGIC CONTACT (DASHED WHERE INFERRED)

FAULT – NOT ALL FAULTS ARE SHOWN FOR CLARITY OF PRESENTATION; U/D INDICATES RELATIVE MOVEMENT (UP, DOWN).

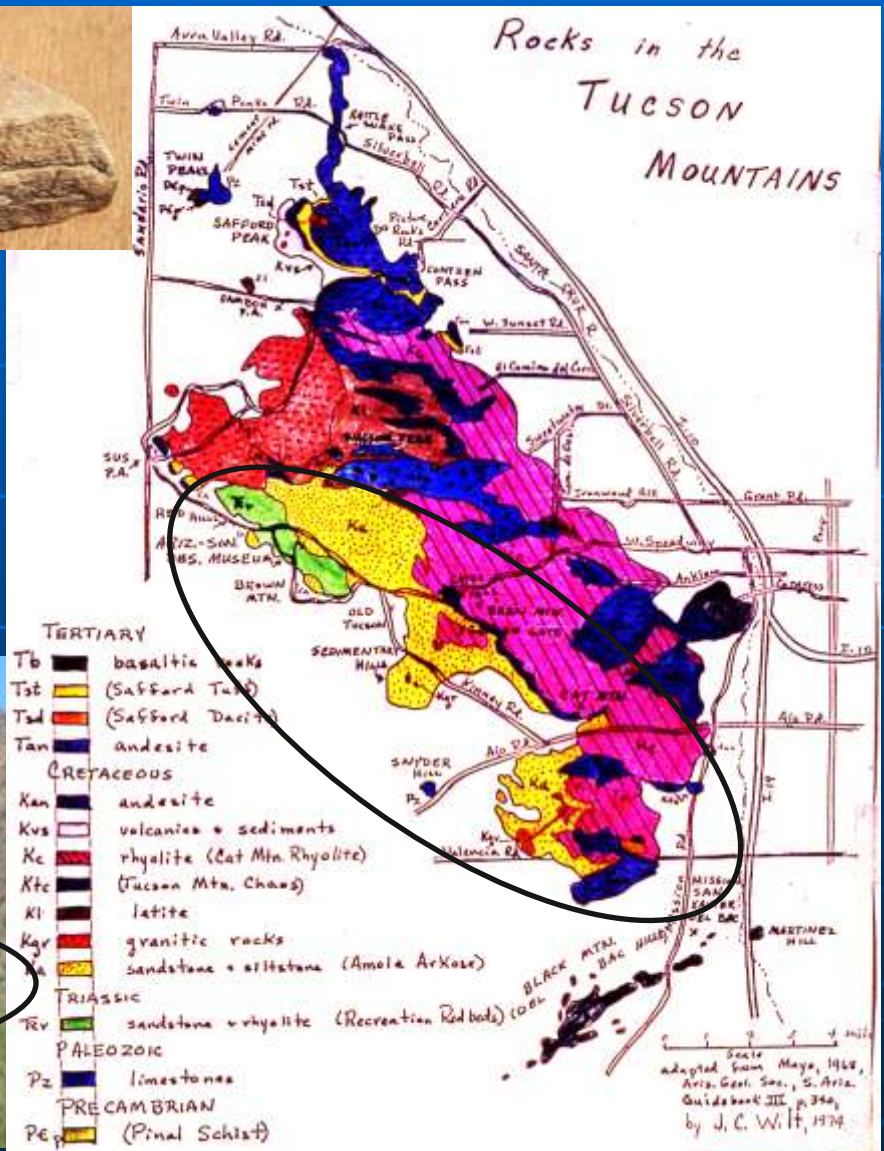
NOTES:
1. CROSS-SECTION REPRESENTS FACILITIES AT PROPOSED DESIGN (21 YEARS)
2. GEOLOGY COMPILED BY SRK CONSULTING, 2010

GEOLOGY SOURCE DATA
1. JOHNSON AND FERGUSON, 2006, AZGS DGM 59
2. H. DREWES, 1971, USGS PROFESSIONAL PAPER 658–C
3. H. DREWES, 2002 (USGS MAP)
4. TETRA TECH, 2007
5. ROSEMONT COPPER

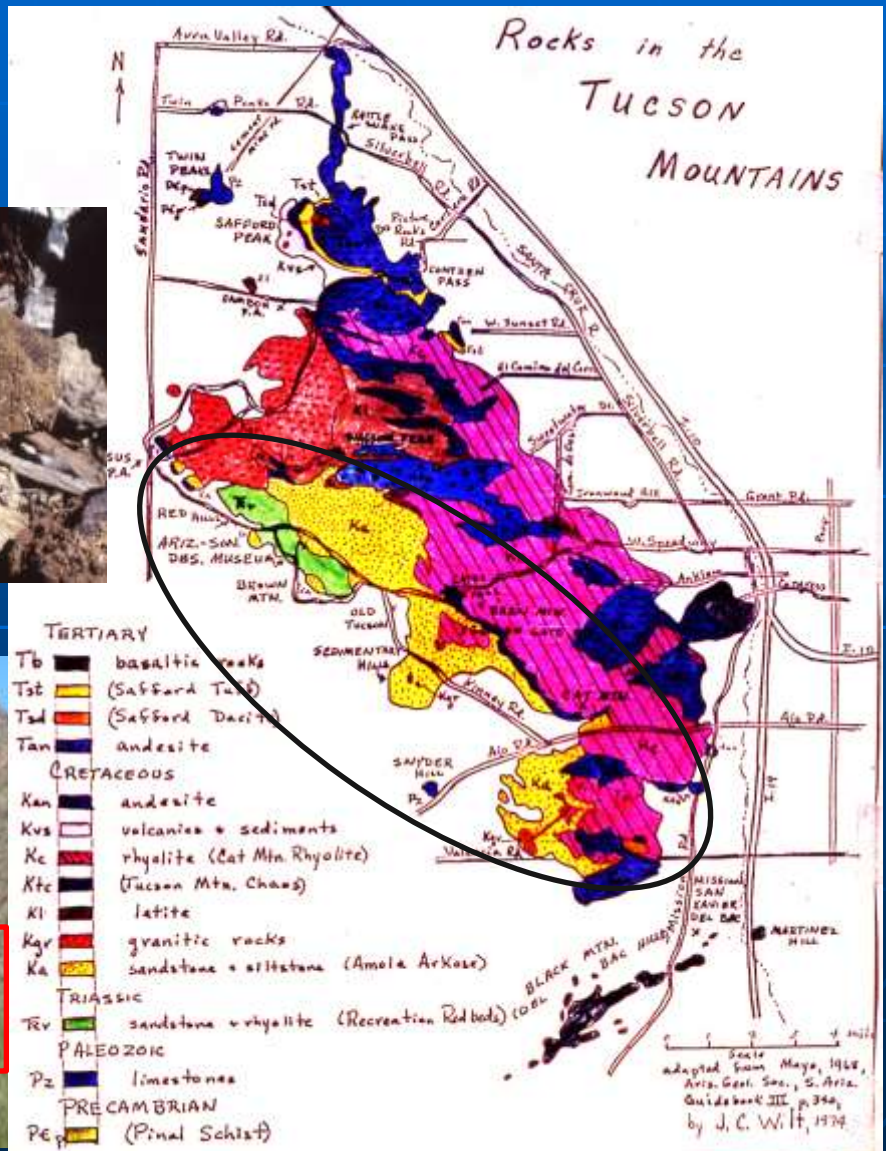
SCALE 1100' 0 1100' 2200'
NO VERTICAL EXAGGERATION

A REVISION

Late Mesozoic – Early Cretaceous Tucson Mts. – Amole Arkose

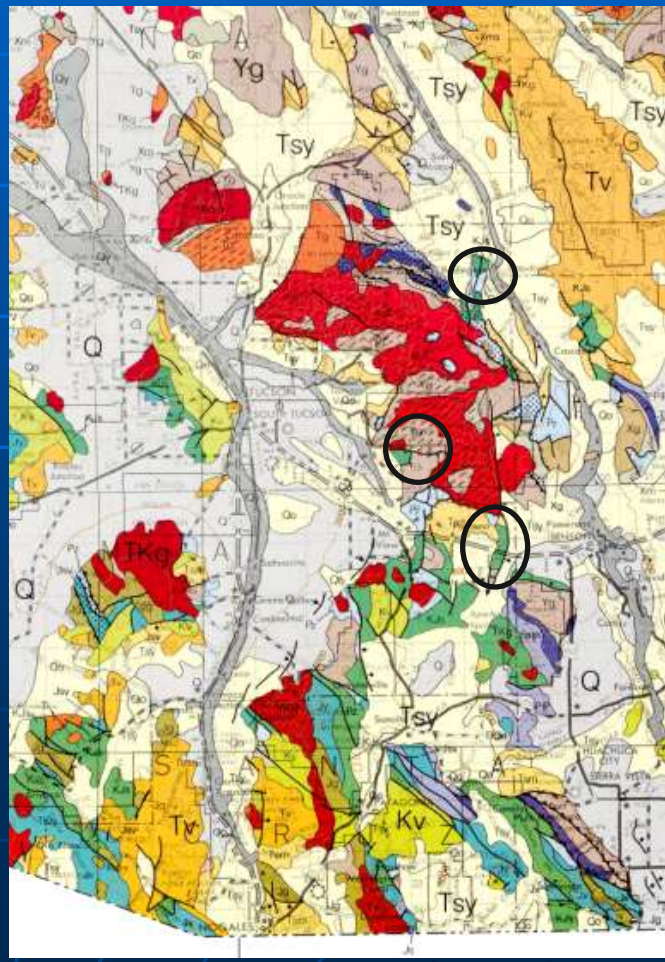


Late Mesozoic – Early Cretaceous Tucson Mts. – Amole Arkose



Late Mesozoic – Early Cretaceous

Catalina - Rincon Mts. – Bisbee Group



Bisbee Group – S. of Rincons

Bisbee Group, Mural Limestone 100 Ma

Ledge of Limestone south of Bisbee, in center of Bisbee basin

- Marine limestone did not extend much further north than Mule Mts.
- Thick rudistid (clam) reefs south of Bisbee

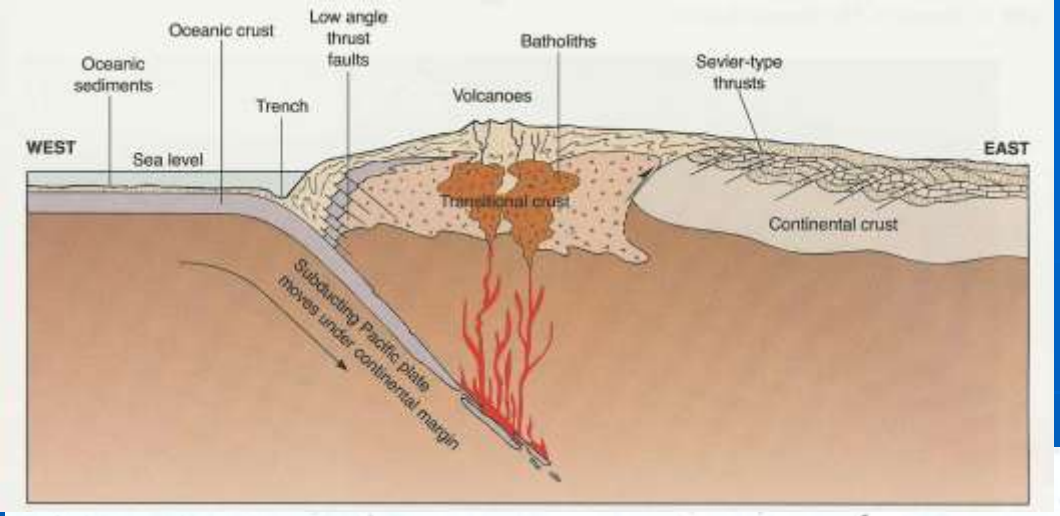
FIGURE 11-11 *Lovadiaites dorsiboni*, a Cretaceous rudistid bivalve from Texas. Rudistids appeared in the Jurassic and proliferated during the Cretaceous, when they were important reef-making organisms. They bear a close resemblance to some Paleozoic corals. This specimen is 8.6 centimeters tall.

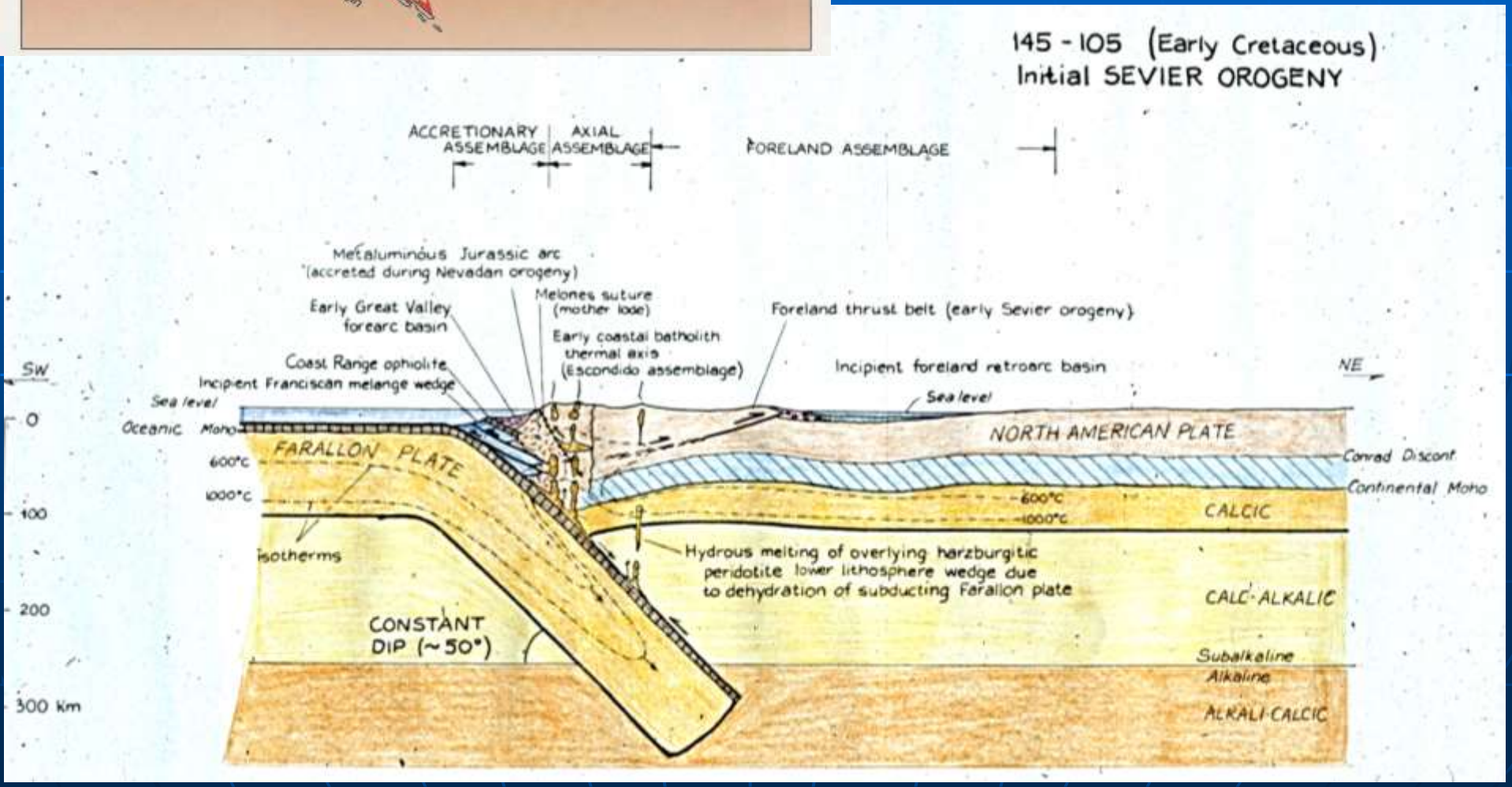
Sevier Orogeny (mountain building) 90-70 Ma)

OROGENY	OROGENIC PHASE	ASSEMBLAGES	MAGMATISM	TECTONICS	MINERAL RESOURCES	EPOCH	TIME
SAN ANDREAS	Basin & Range	Basin & Range	basaltic volcanism	grabens	salt, cinders, sand gypsum, zeolites	PLIOCENE	0-13
	Transverse	Transverse	none or rare	en echelon folds trending NE-SW	petroleum, gas	PLIOCENE	0-13
GALIURO	Culminant Galiuro	Whipple	local qtz. alkalic volcanics	gravity slide detachments	Cu-Au-Ag in detach. flts; Au vns	mid-MIOCENE up OLIGOCENE	28-13
	Medial Galiuro	Galiuro	alkali-calcic volc. & dikes	NW-trend folds NW dikes	Pb-Zn-Ag vns Au vns	MIOCENE	38-18
	Initial Galiuro	Mineta	rare volcanics coarse clastics	local basins little data	U, Cu clastics	up OLIGOCENE low MIOCENE	38-28
LARAMIDE	Culminant Laramide	Echo Park Green River Rim Wilderness Crocopia	peraluminous calcic & calc-alk.	SW-dir. thrusts	Au vns & dissem. W, base metals	EOCENE	56-43
	Medial Laramide	Morenci	calc-alkalic dikes & stocks	NE dikes & veins	porphyry copper	EOCENE PALEOCENE	75-50
	Initial Laramide	Denver Tombstone Laramie	alkali-calcic volc. & stocks alkalic stocks	NE dir. folds & thrusts NE-shorelines	Pb-Zn-Ag coal	CRETACEOUS PALEOCENE CRETACEOUS	80-60 85-65
		Hillsboro	& volcanics	E-W wedge uplifts	Cu-Au		
SEVIER			alkalic stocks	S or E dir. thrusts	Au-Cu	CRETACEOUS	105-65

Table 1. General framework of Cretaceous and Cenozoic orogenesis in Arizona.

Sevier orogeny





Late Mesozoic – Cretaceous

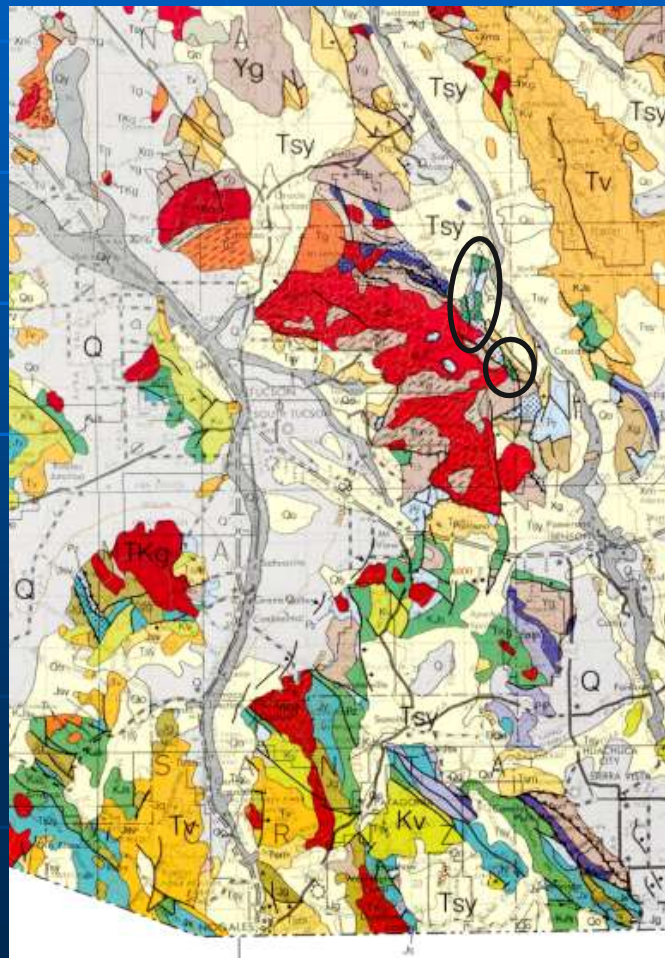
Santa Catalina Mts. – sediments

American Flag Formation – alluvial fans

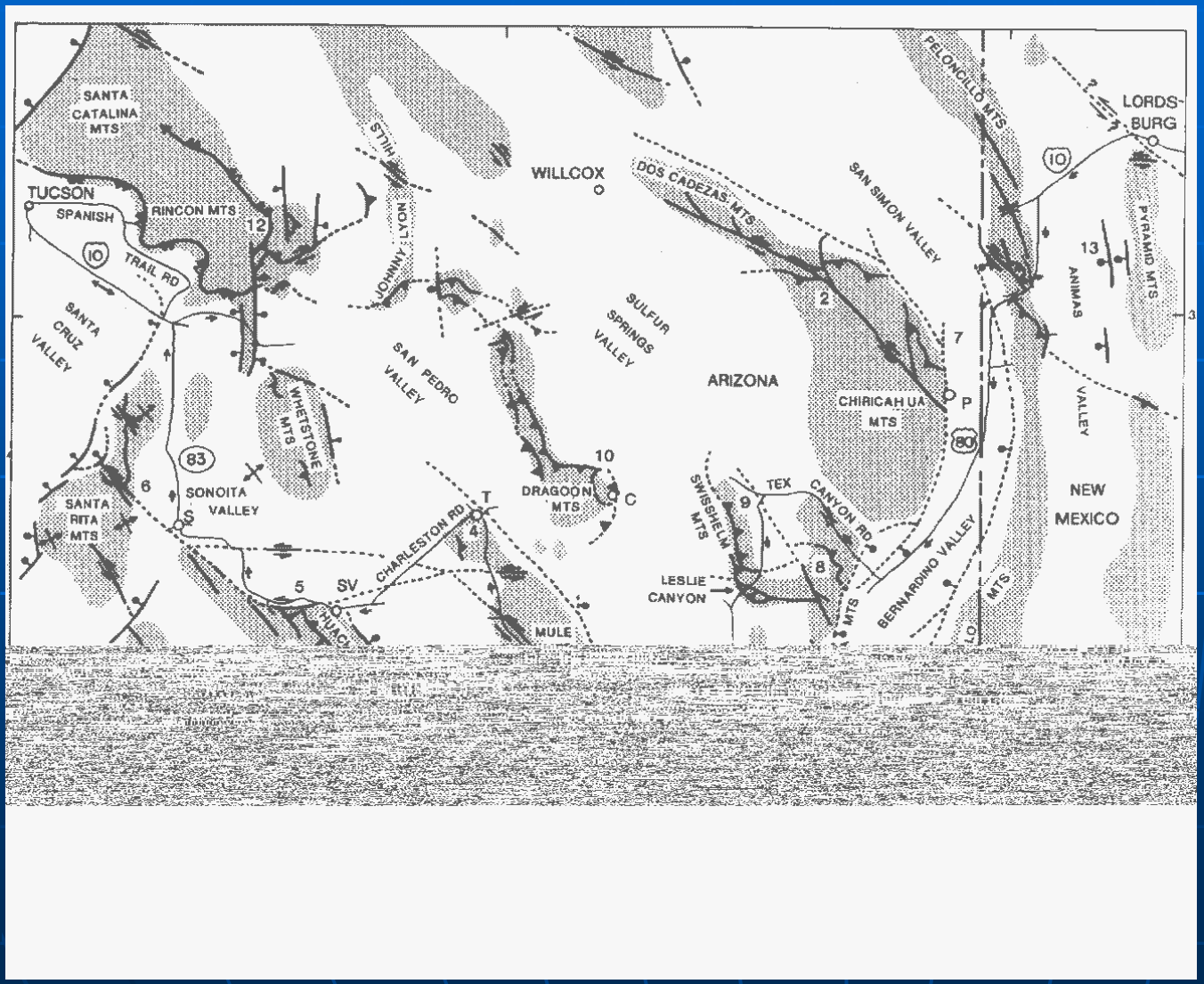
Upper American Flag Fm. =Conglomerate with clasts of porphyry, Precambrian granite, sandstone, and volcanic rocks

Middle American Flag Fm. = Conglomerates with Oracle Granite, Barnes Congl., and quartzite clasts

Lower American Flag Fm. = Limestone-cobble conglomerate with phyllite and sandstone



Sawmill Canyon fault zone



Early Laramide Orogeny (mountain building) – 75-70 Ma)

OROGENY	OROGENIC PHASE	ASSEMBLAGES	MAGMATISM	TECTONICS	MINERAL RESOURCES	EPOCH	TIME
SAN ANDREAS	Basin & Range	Basin & Range	basaltic volcanism	grabens	salt, cinders, sand gypsum, zeolites	PLIOCENE	0-13
	Transverse	Transverse	none or rare	en echelon folds trending NE-SW	petroleum, gas	PLIOCENE	0-13
GALIURO	Culminant Galiuro	Whipple	local qtz. alkalic volcanics	gravity slide detachments	Cu-Au-Ag in detach. flts; Au vns	mid-MIOCENE up OLIGOCENE	28-13
	Medial Galiuro	Galiuro	alkali-calcic volc. & dikes	NW-trend folds NW dikes	Pb-Zn-Ag vns Au vns	MIOCENE	38-18
	Initial Galiuro	Mineta	rare volcanics coarse clastics	local basins little data	U, Cu clastics	up OLIGOCENE low MIOCENE	38-28
LARAMIDE	Culminant Laramide	Echo Park Green River Rim Wilderness Crocopia	peraluminous calcic & calc-alk.	SW-dir. thrusts	Au vns & dissem. W, base metals	EOCENE	56-43
	Medial Laramide	Morenci	calc-alkalic dikes & stocks	NE dikes & veins	porphyry copper	EOCENE PALEOCENE	75-50
	Initial Laramide	Denver Tombstone Laramie Hillsboro	alkali-calcic volc. & stocks alkalic stocks & volcanics	NE dir. folds & thrusts NE-shorelines E-W wedge uplifts	Pb-Zn-Ag coal Cu-Au	CRETACEOUS PALEOCENE CRETACEOUS	80-60 85-65
SEVIER			alkalic stocks	S or E dir. thrusts	Au-Cu	CRETACEOUS	105-85

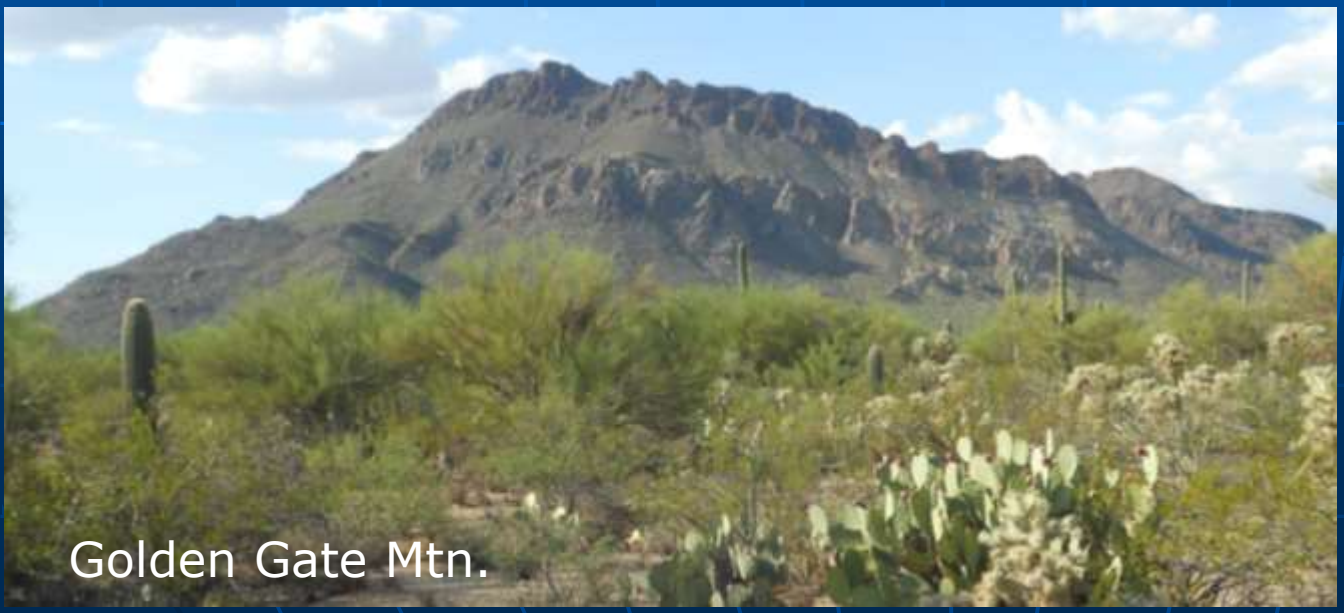
Table 1. General framework of Cretaceous and Cenozoic orogenesis in Arizona.

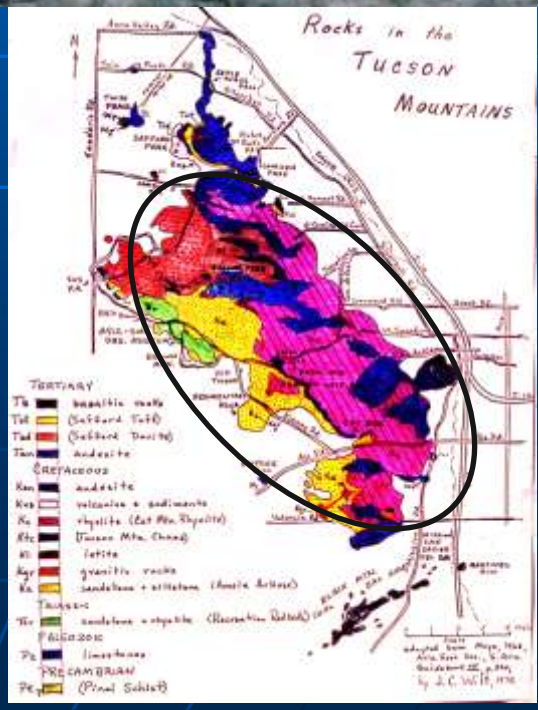
Latest Cretaceous – Early Laramide orogeny - volcanics, calderas, mountains (90-65 Ma)

Late Mesozoic – Early Cretaceous Tucson Mts. – Cat Mtn. Rhyolite 74 Ma

Gates Pass

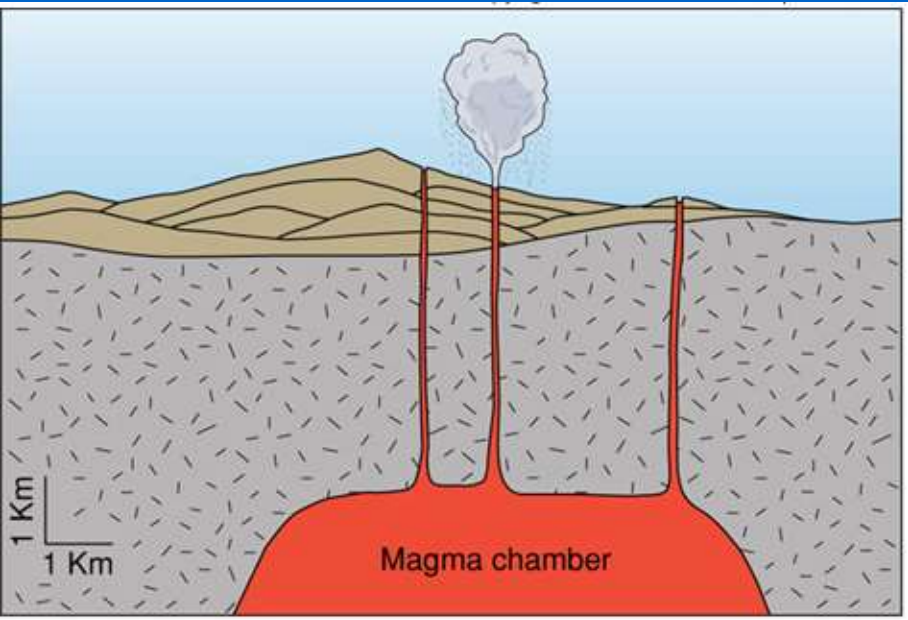
Cat Mtn.


Golden Gate Mtn.

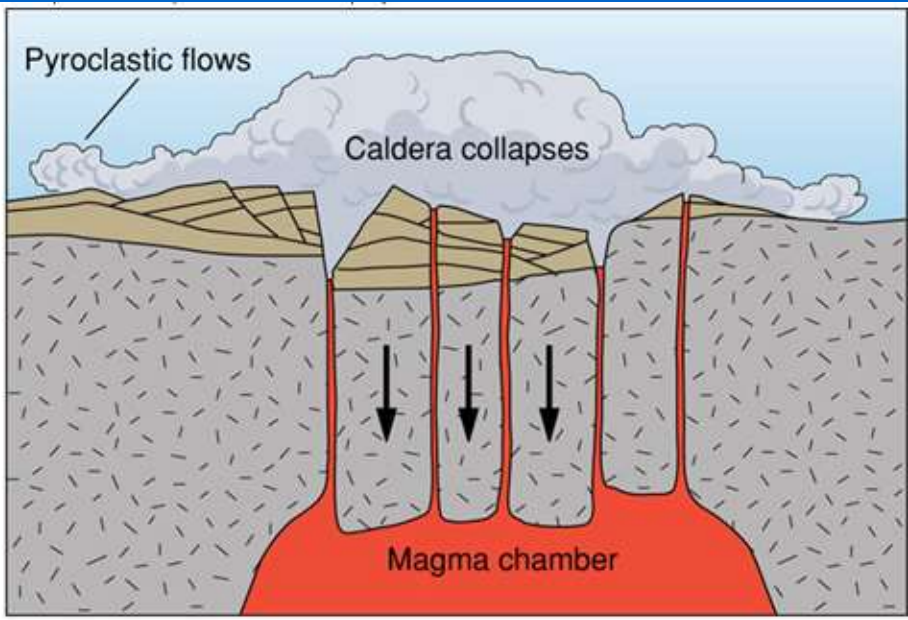


Mt. Pinatubo 1991

Crater Lake



A



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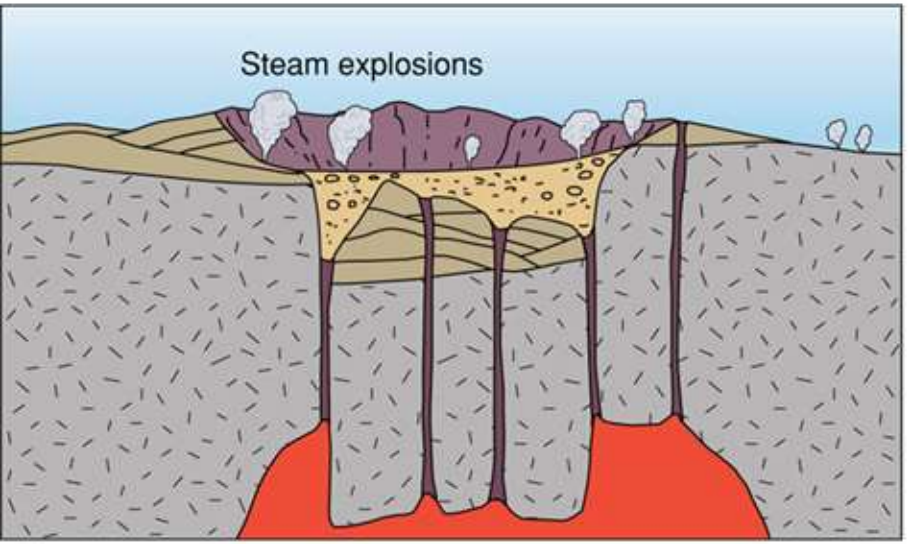
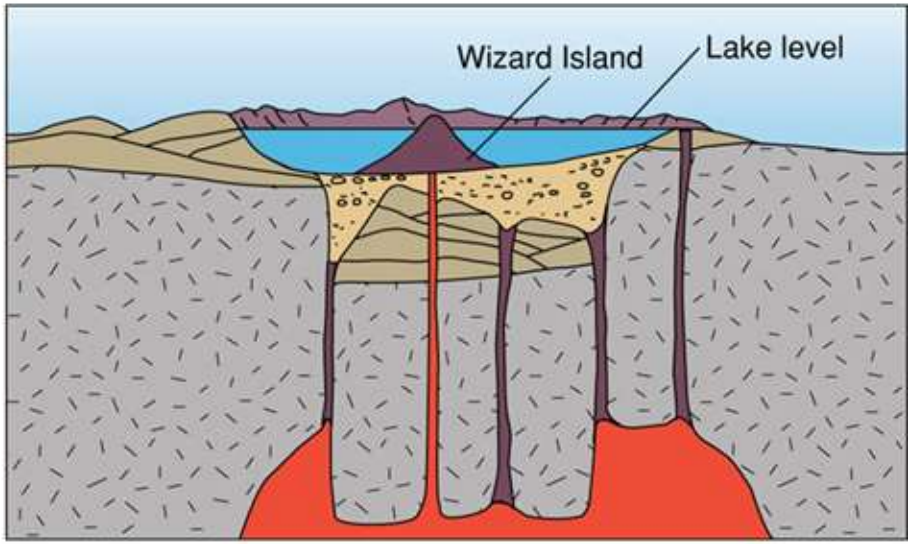
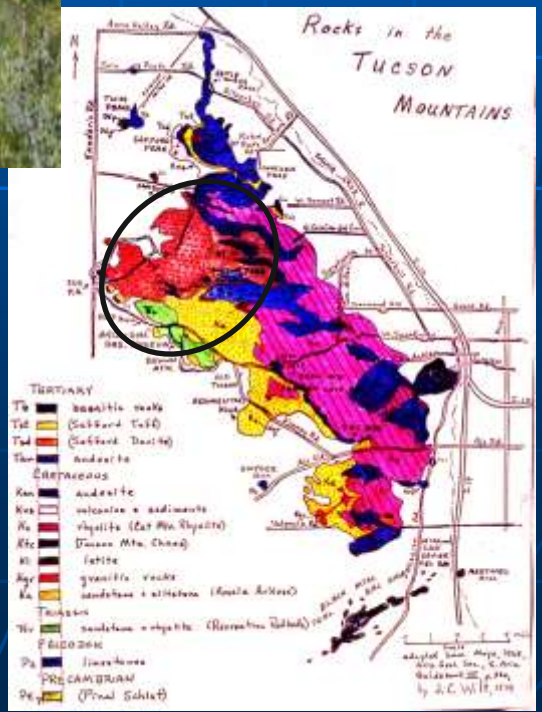
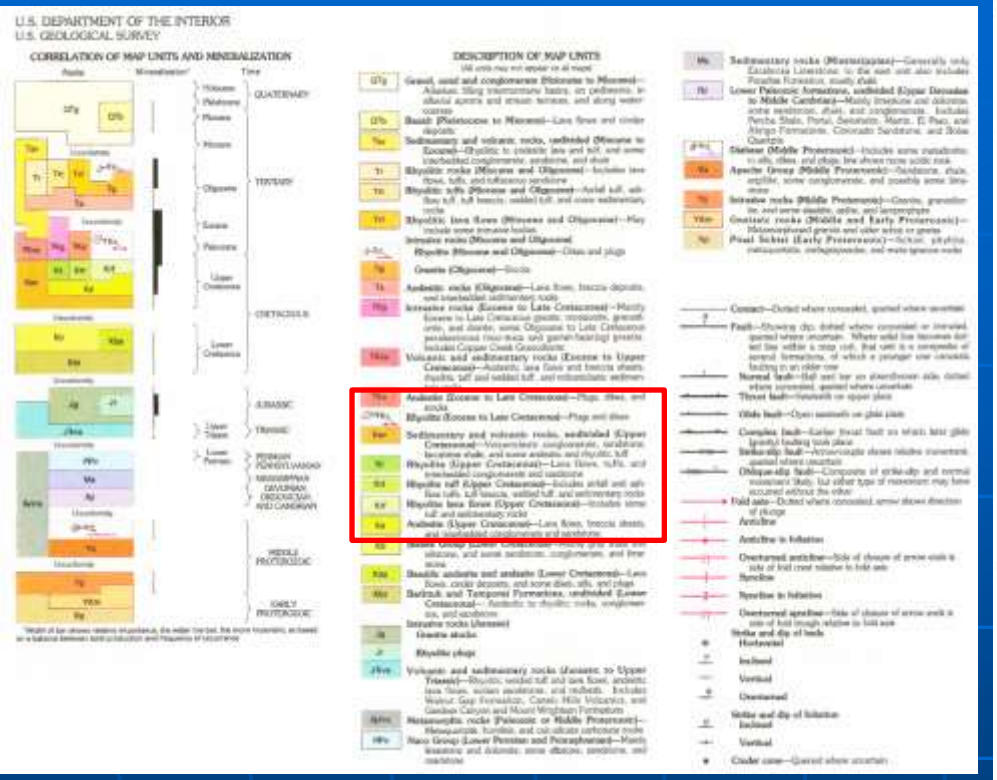


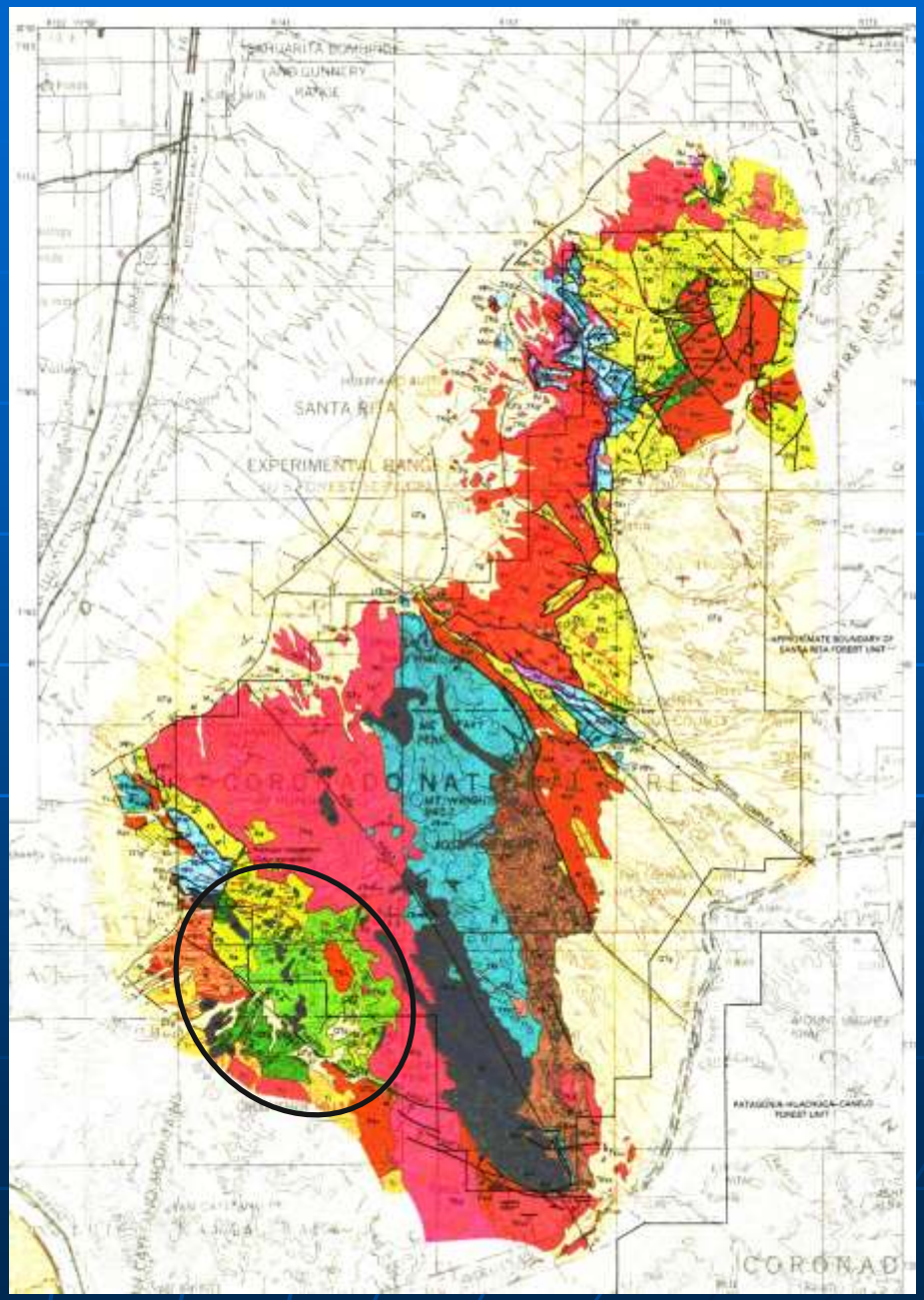


Late Mesozoic – Cretaceous
Tucson Mts. – Amole Granite



Late Cretaceous volc. & sed. rocks – Santa Rita Mts.



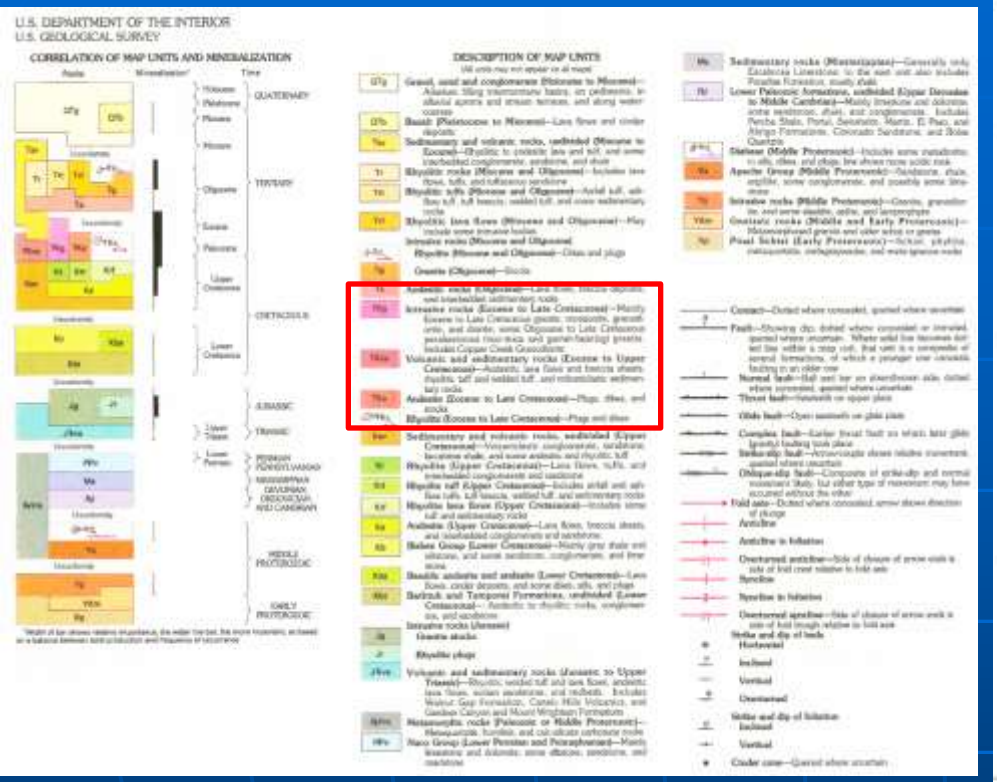


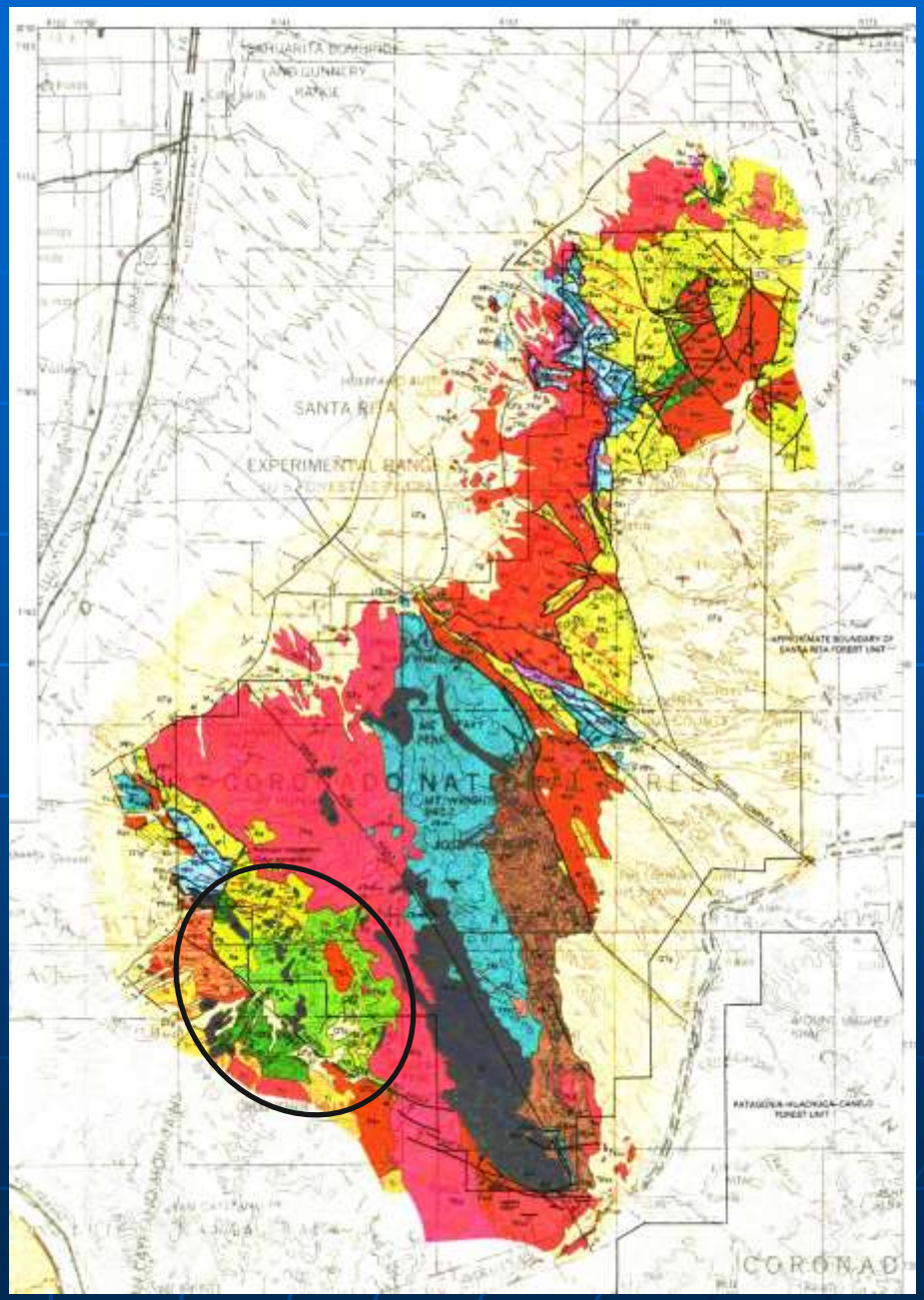
Fort Crittenden Fm. – rhyolite tuff, conglomerate, shale

Salero Fm. – sedimentary and volcanic rocks, tuff 72.5 Ma

Source: Drewes, 1996, USGS Bull. 2083, plate 4

Latest Cretaceous igneous intrusions – Santa Rita Mts.





Elephant Head Quartz Monzonite - 69 Ma

Madera Canyon Granodiorite – 68 Ma

Josephine Canyon Diorite - 67 Ma

Source: Drewes, 1996, USGS Bull. 2083, plate 4; USGS Prof. Paper 915, 1976

6. TIMES OF CRUSTAL UNREST

SANTA CATALINA MOUNTAINS REGION
late Mesozoic and early Cenozoic Eras
(~150-40 million years ago)

The Mesozoic Era was the time of the dinosaurs, but no evidence of them has yet been found in the Santa Catalina Mountains. Perhaps this is because the geologic record of our region became very complex during the middle and late Mesozoic Era:

We do know that by this time most of this region had once again emerged from the seas. Near Peppersauce Cave, in the northern Santa Catalinas, sedimentary rocks of Cretaceous age are present. These strata are known as **Glance Conglomerate** and **American Flag Formation.**

Glance Conglomerate contains angular fragments of late Paleozoic limestones. American Flag Formation contains rounded cobbles of early Paleozoic quartzite and boulders of Precambrian granite. We can thus infer that these sediments were probably deposited in **alluvial fans,** not far from their high-standing, rugged source terrain. Some strata of American Flag Formation were deposited in an arm of the sea.

Faulting and mountain building must have occurred not long before, and very close by — perhaps to the north, along the Mogul Fault. To the south, the Geesaman Fault was also probably active during this time.

Near where Mt. Lemmon and Marble Peak are today, a large mass of dark igneous rock known as **Leatherwood quartz diorite** was emplaced during the mid-Mesozoic at great depth within the earth's crust. A large volcano probably formed on the earth's surface at this site, but the only evidence for it today is the great diorite pluton which formed beneath it. Leatherwood quartz diorite can be recognized by its distinctive content of tiny, glassy, lime-green **epidote** crystals, and equally small crystals of khaki-colored **apatite.**

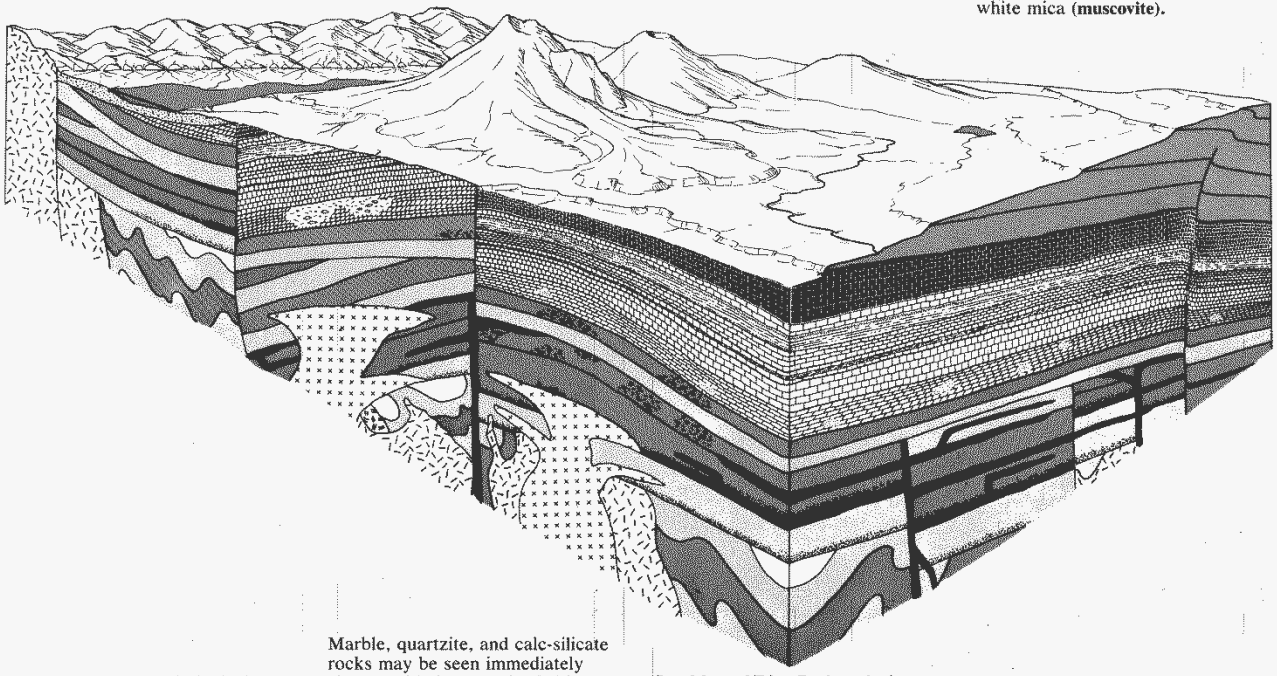
Sill-like masses of Leatherwood quartz diorite intruded layered rocks south and west of the main volcano/pluton, in what is now the Santa Catalina "forerange".

Intense heat from various Leatherwood intrusions metamorphosed much of the overlying sandstone, shale, and limestone. Some of the resulting metamorphic rocks — quartzite, calc-silicates, and schist — can now be seen in road cuts at the Mt. Lemmon Ski Area. Metamorphosed late Paleozoic limestone forms the white marble that caps Marble Peak.

Farther north in the Santa Catalinas, a mass of **andesite porphyry** was emplaced at about this same time. At some places this andesite porphyry brought with it a valuable content of copper and other metals. This ore is mined near the town of Mammoth, and is smelted into copper metal at San Manuel. **San Manuel andesite porphyry** is usually grey where excavated in the mine, but surface exposures of related rocks in the northern Santa Catalinas are usually thoroughly altered to have a greenish color. In that area this formation is known to some as **Rice Peak andesite porphyry.**

At a somewhat later time, deep within the earth's crust to the south of the main intrusion of Leatherwood quartz diorite, a large mass of garnet-bearing granite formed. This white granite is known as **Wilderness granite,** and is found today mainly in the "Wilderness of Rocks", south of Mt. Lemmon.

Most good exposures of Wilderness granite are accessible only by trails, but you can examine a variety of this rock along the highway at the General Hitchcock Picnic Area. Wilderness granite is noteworthy for its wine-red garnets, but is also unusual in that it contains crystals of BOTH black mica **(biotite)** AND white mica **(muscovite).**



American Flag Formation and Glance Conglomerate are present in the low area at the top of the exhibit wall on either side of the fault to the immediate left of panel #5.

Additional faults are represented to the left and to the lower right of panel #5.

Leatherwood quartz diorite is the dark rock that forms the bulk of the exhibit wall below and to either side of this panel.

Marble, quartzite, and calc-silicate rocks may be seen immediately above and below panel #5. The white rock at the top of the wall directly above the right corner of panel #5 is marble.

San Manuel/Rice Peak andesite porphyry is the greenish rock displayed in the exhibit wall below the next panel.

Wilderness granite forms the crest of the exhibit wall above and to the right of this panel.

art work by LINDA CAREY and CHARLOTTE ERNSTEIN; prepared for TOHONO CHUL PARK © 1986 by D.W. SHAKEL

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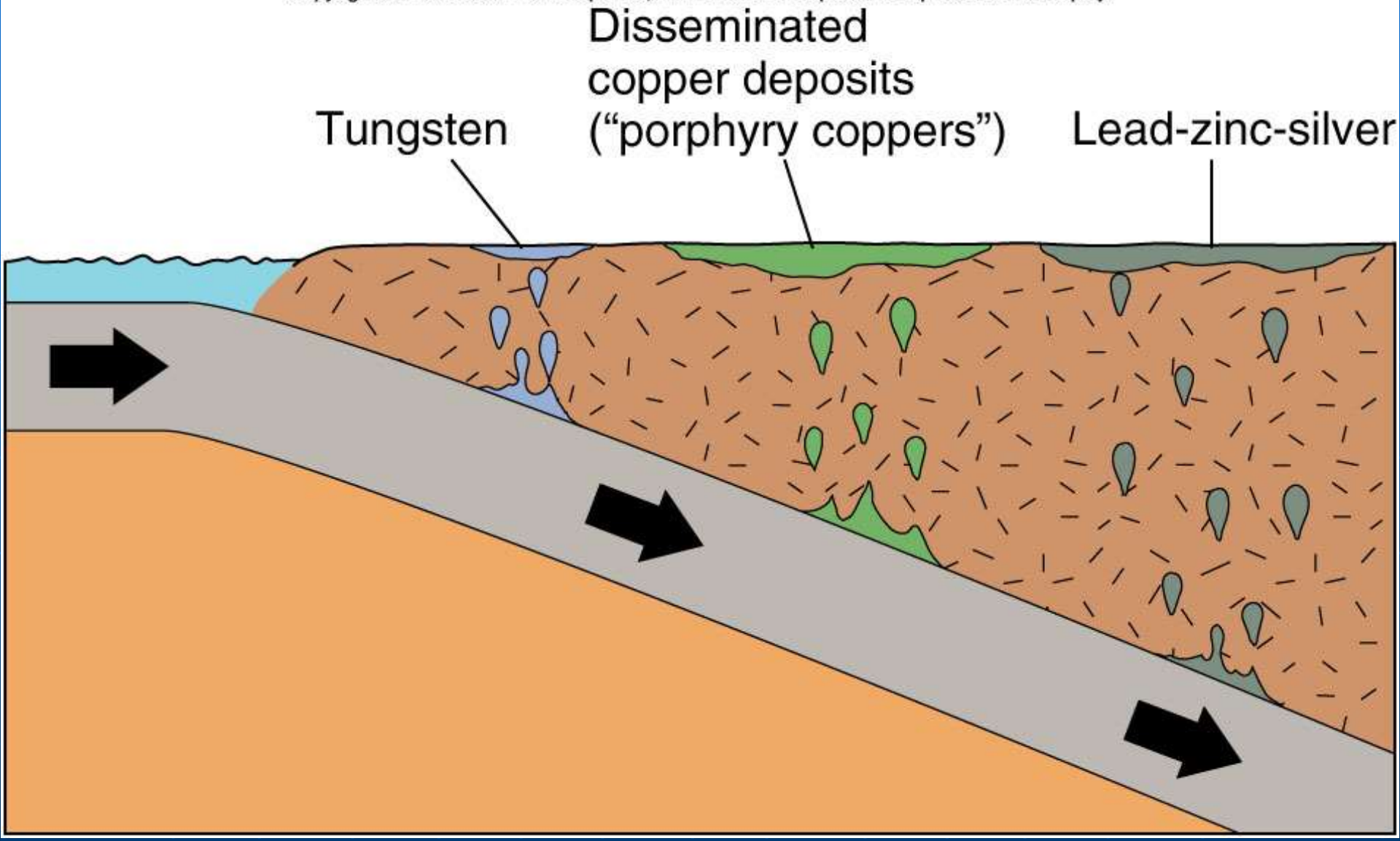
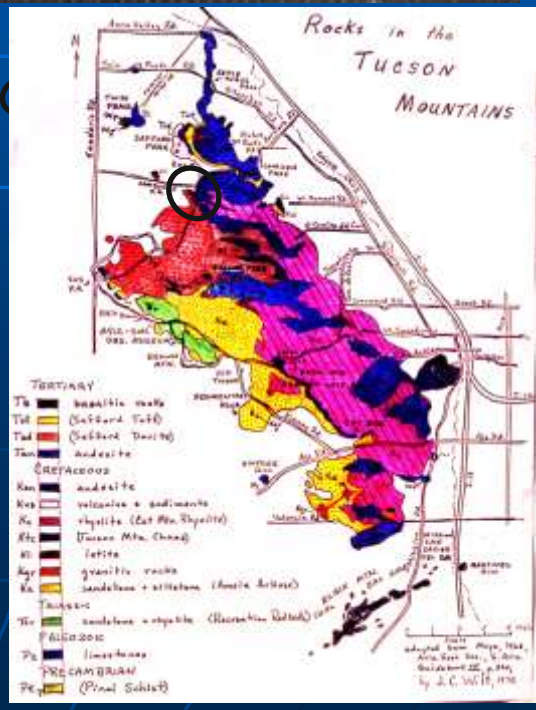


Late Mesozoic – Late Cretaceous Tucson Mts. – Old Yuma Mine

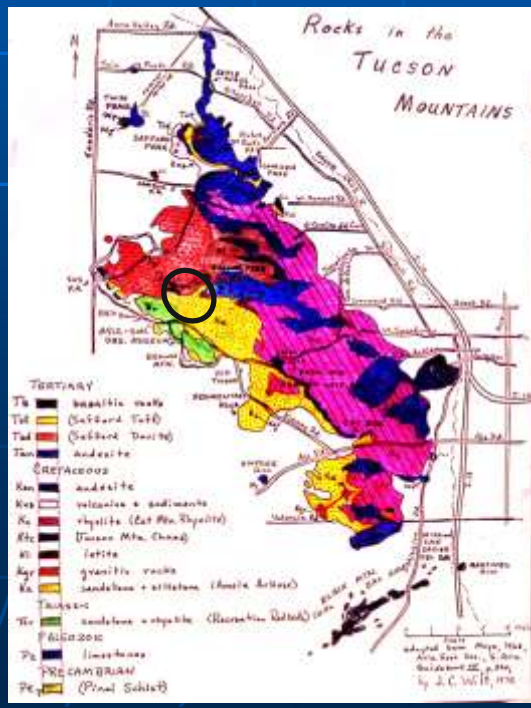
wulfenite

vanadinite

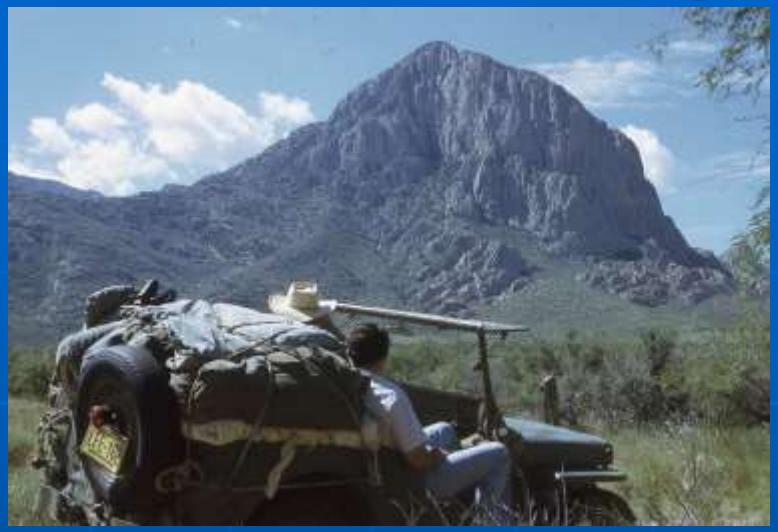


Silver lead zinc mines

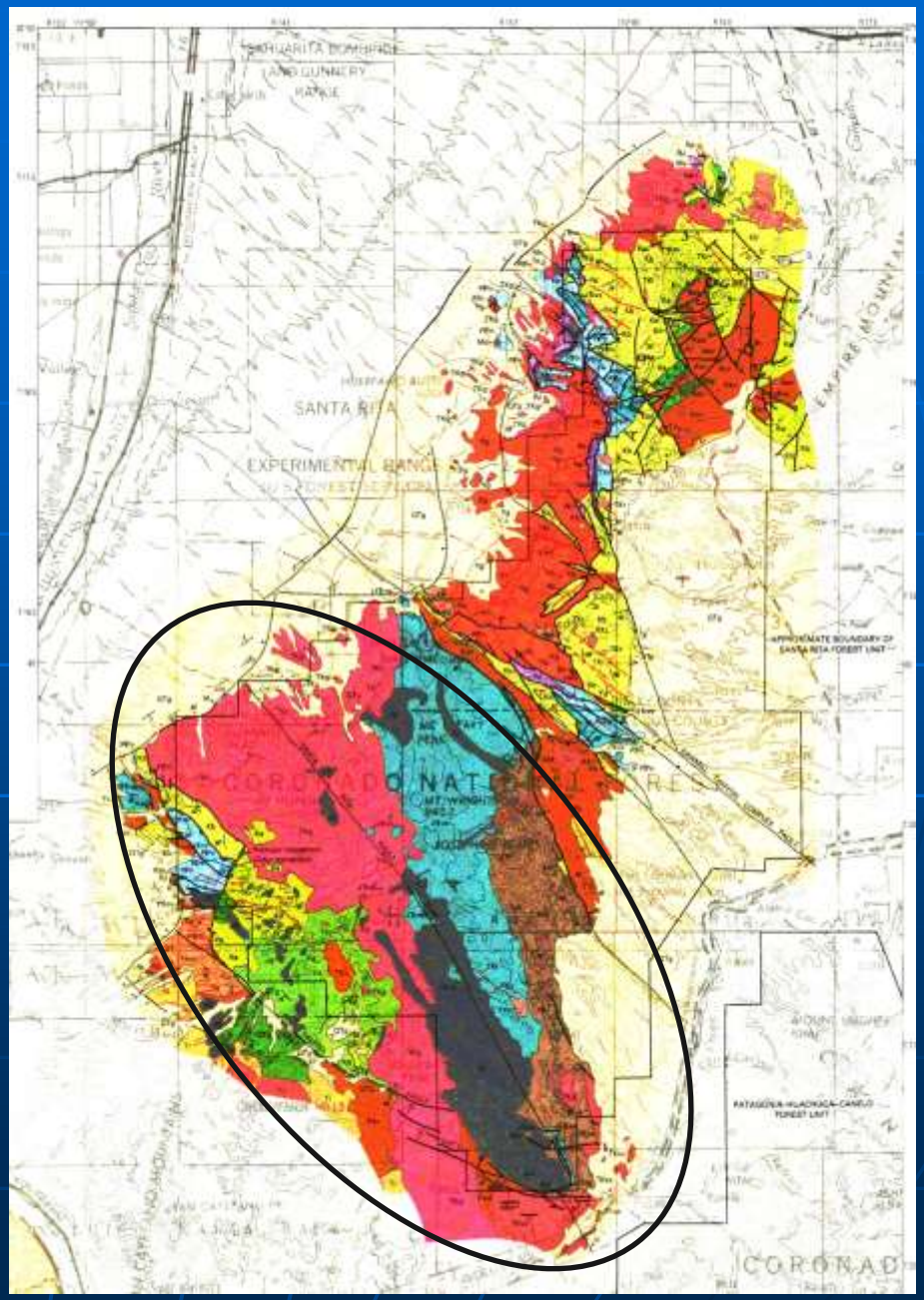
Mile Wide mine North of ASDM



Latest Cretaceous igneous intrusions – Santa Rita Mts.



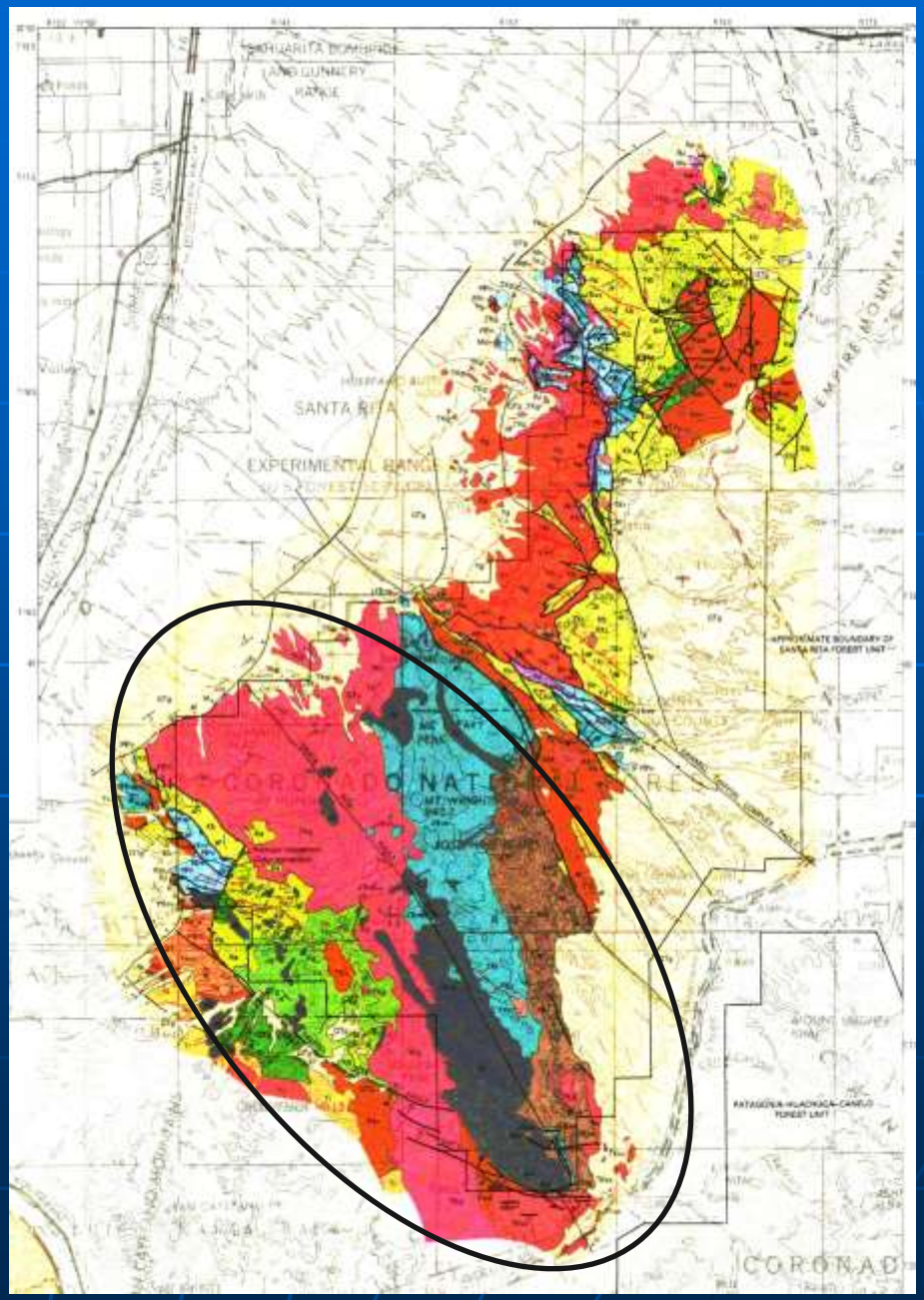
Elephant Head Quartz Monzonite 68 Ma



Source: Drewes, 1996, USGS Bull. 2083, plate 4

Latest Cretaceous igneous intrusions – Santa Rita Mts.

Madera Canyon Granodiorite 68 Ma

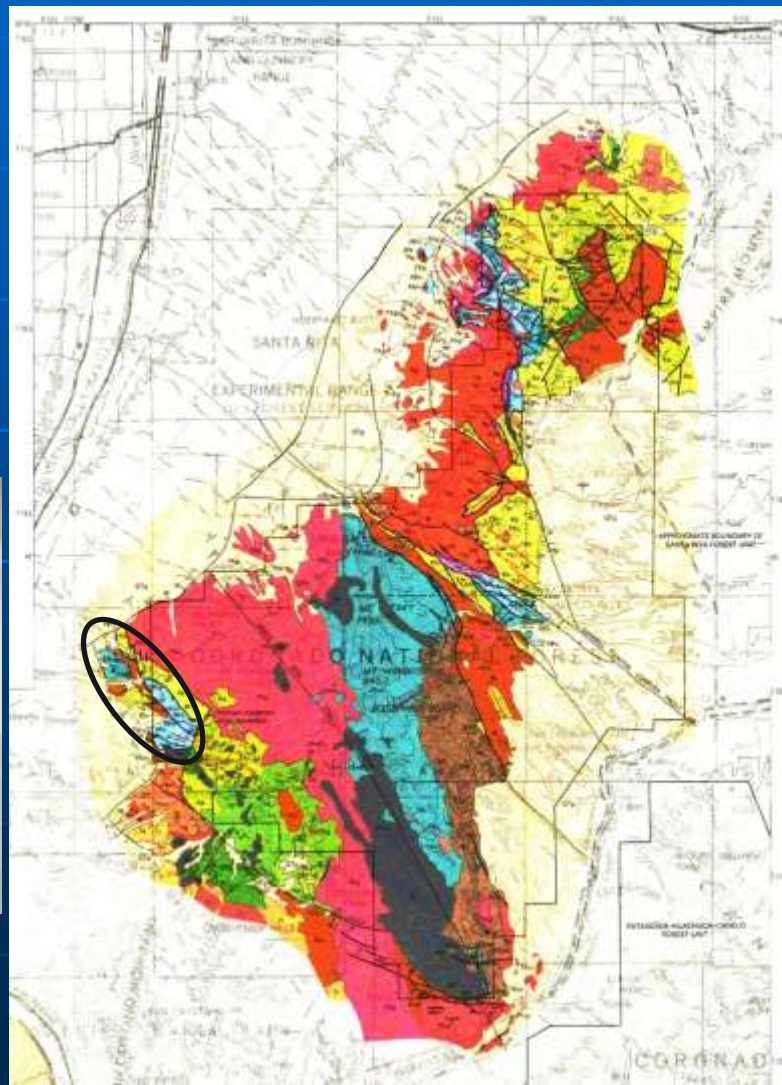


Source: Drewes, 1996, USGS Bull. 2083, plate 4

Late Mesozoic – Late Cretaceous – Santa Rita Mts.

Glove Mine

Wulfenite $Pb(MoO_4)$

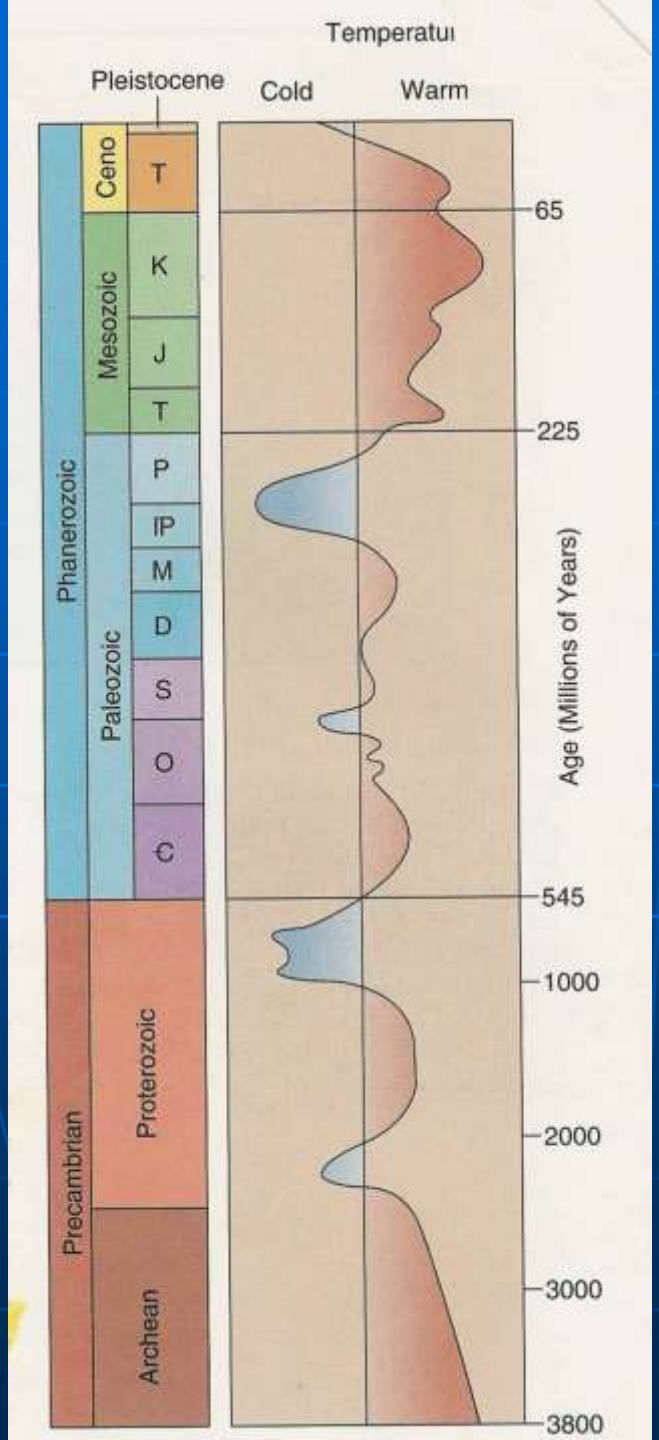


Middle Laramide Orogeny (mountain building) – 65-55 Ma)

OROGENY	OROGENIC PHASE	ASSEMBLAGES	MAGMATISM	TECTONICS	MINERAL RESOURCES	EPOCH	TIME
SAN ANDREAS	Basin & Range	Basin & Range	basaltic volcanism	grabens	salt, cinders, sand gypsum, zeolites	PLIOCENE	0-13
	Transverse	Transverse	none or rare	en echelon folds trending NE-SW	petroleum, gas	PLIOCENE	0-13
GALIURO	Culminant Galiuro	Whipple	local qtz. alkalic volcanics	gravity slide detachments	Cu-Au-Ag in detach. flts; Au vns	mid-MIOCENE up OLIGOCENE	28-13
	Medial Galiuro	Galiuro	alkali-calcic volc. & dikes	NW-trend folds NW dikes	Pb-Zn-Ag vns Au vns	MIOCENE	38-18
	Initial Galiuro	Mineta	rare volcanics coarse clastics	local basins little data	U, Cu clastics	up OLIGOCENE low MIOCENE	38-28
LARAMIDE	Culminant Laramide	Echo Park Green River Rim Wilderness Crocopia	peraluminous calcic & calc-alk.	SW-dir. thrusts	Au vns & dissem. W, base metals	EOCENE	56-43
	Medial Laramide	Morenci	calc-alkalic dikes & stocks	NE dikes & veins	porphyry copper	EOCENE PALEOCENE	75-50
	Initial Laramide	Denver Tombstone Laramie Hillsboro	alkali-calcic volc. & stocks alkalic stocks & volcanics	NE dir. folds & thrusts NE-shorelines E-W wedge uplifts	Pb-Zn-Ag coal Cu-Au	CRETACEOUS PALEOCENE CRETACEOUS	80-60 85-65
SEVIER			alkalic stocks	S or E dir. thrusts	Au-Cu	CRETACEOUS	105-65

Table 1. General framework of Cretaceous and Cenozoic orogenesis in Arizona.

Geologic Time Scale



EON	ERA	PERIOD		EPOCH		Ma
Phanerozoic	Cenozoic	Quaternary		Holocene		0.01
				Pleistocene	Late	0.8
					Early	1.8
		Tertiary	Neogene	Pliocene	Late	3.6
					Early	5.3
				Miocene	Late	11.2
					Middle	16.4
					Early	33.7
				Oligocene	Late	28.5
					Early	33.7
			Paleogene	Eocene	Late	41.3
					Middle	49.0
					Early	54.8
				Paleocene	Late	61.0
					Early	65.0
	Mesozoic	Cretaceous		Late		99.0
				Early		144
		Jurassic		Late		159
				Middle		180
				Early		206
		Triassic		Late		227
				Middle		242
				Early		248
	Paleozoic	Permian		Late		256
				Early		290
		Pennsylvanian				323
		Mississippian				354
		Devonian		Late		370
				Middle		391
				Early		417
		Silurian		Late		423
				Early		443
		Ordovician		Late		458
				Middle		470
				Early		490
		Cambrian		D		500
				C		512
				B		520
				A		543
zoic	Late					