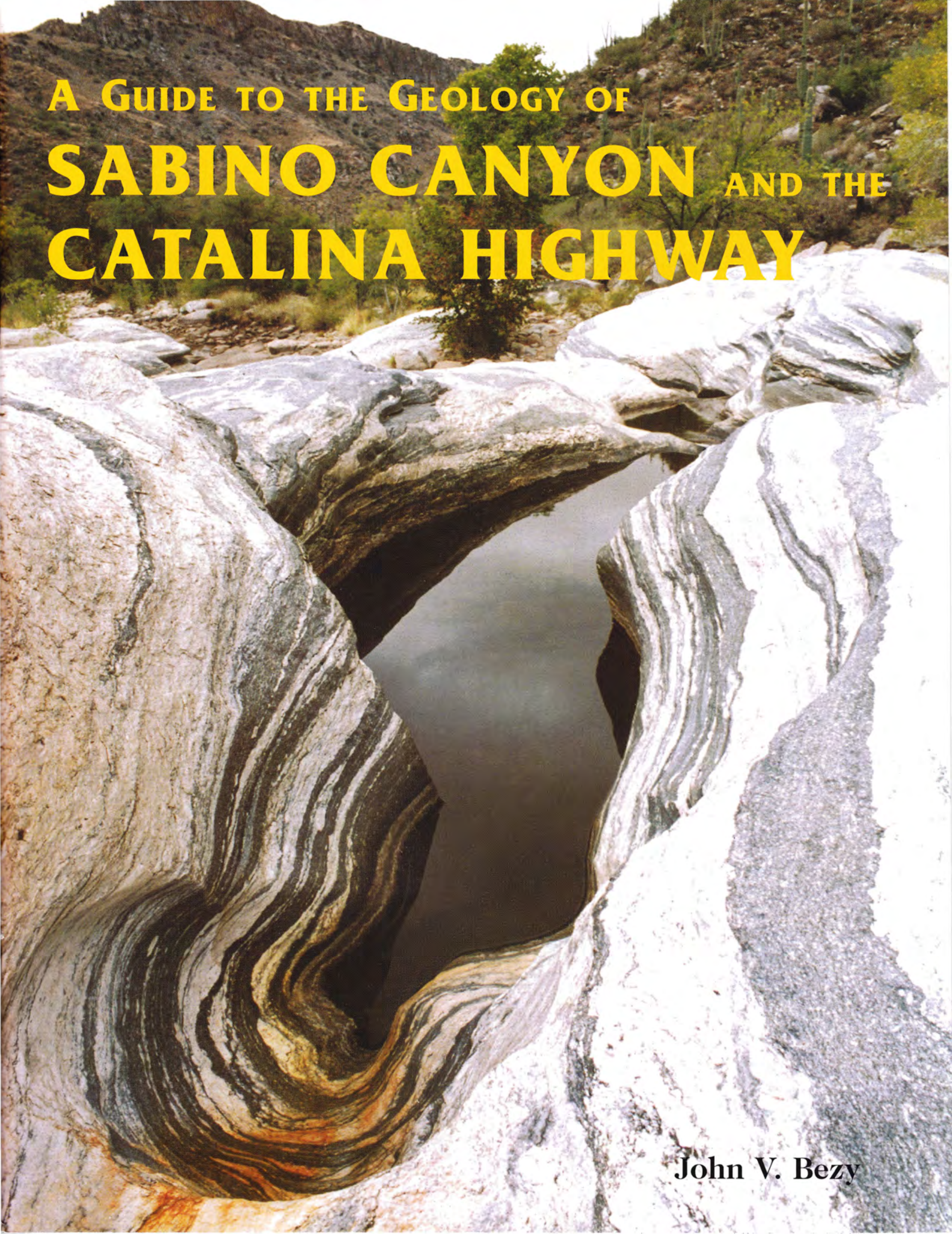
# A GUIDE TO THE GEOLOGY OF SABINO CANYON AND THE CATALINA HIGHWAY



John V. Bezy

# A Guide to the Geology of Sabino Canyon and the Catalina Highway

## CORONADO NATIONAL FOREST

John V. Bezy

The Public Lands Interpretive Association,
Coronado National Forest, National Park Service,
and Arizona Geological Survey worked together
to complete this project.

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On the Cover: A tinaja in gneiss at Shuttle Stop 8 in Sabino Canyon,
Feature SC 10 page 25.

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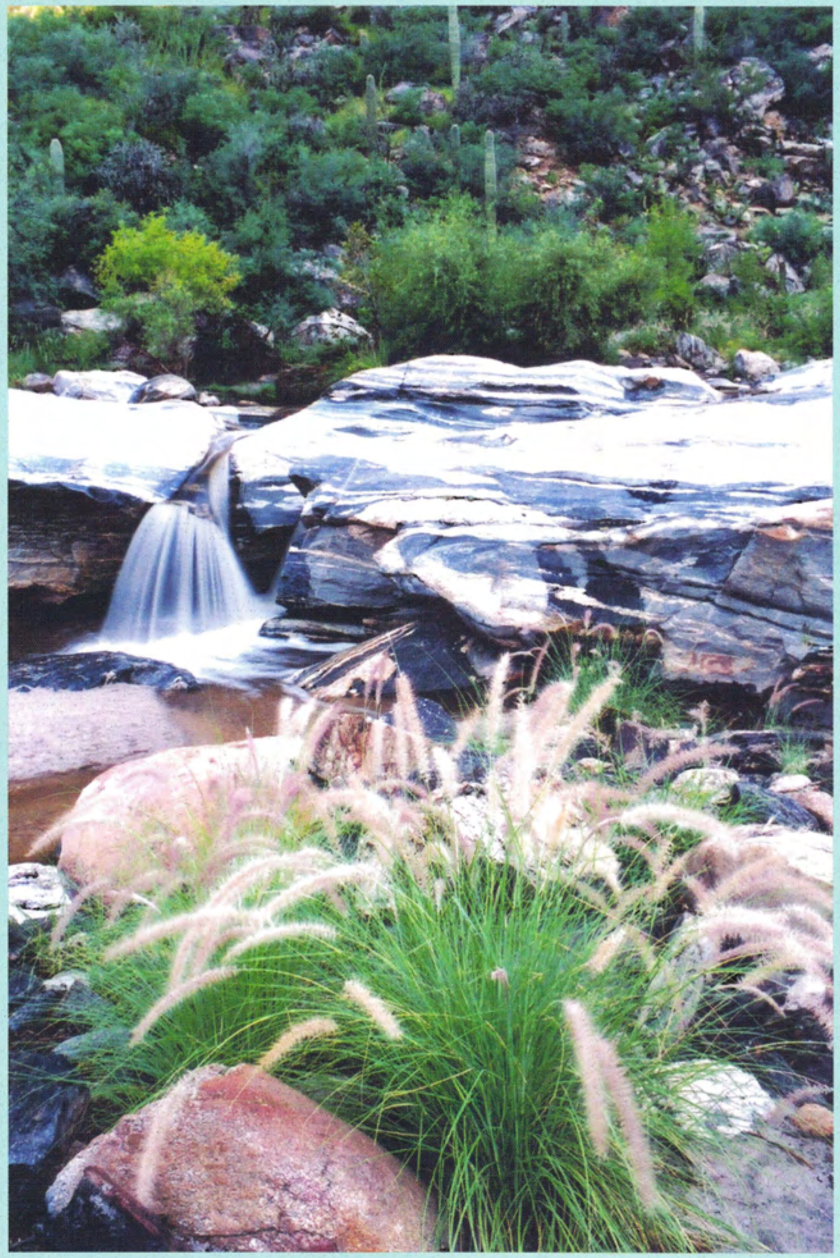
# CONTENTS

Geologic Features along the Catalina Highway—*continued*

## List of Figures



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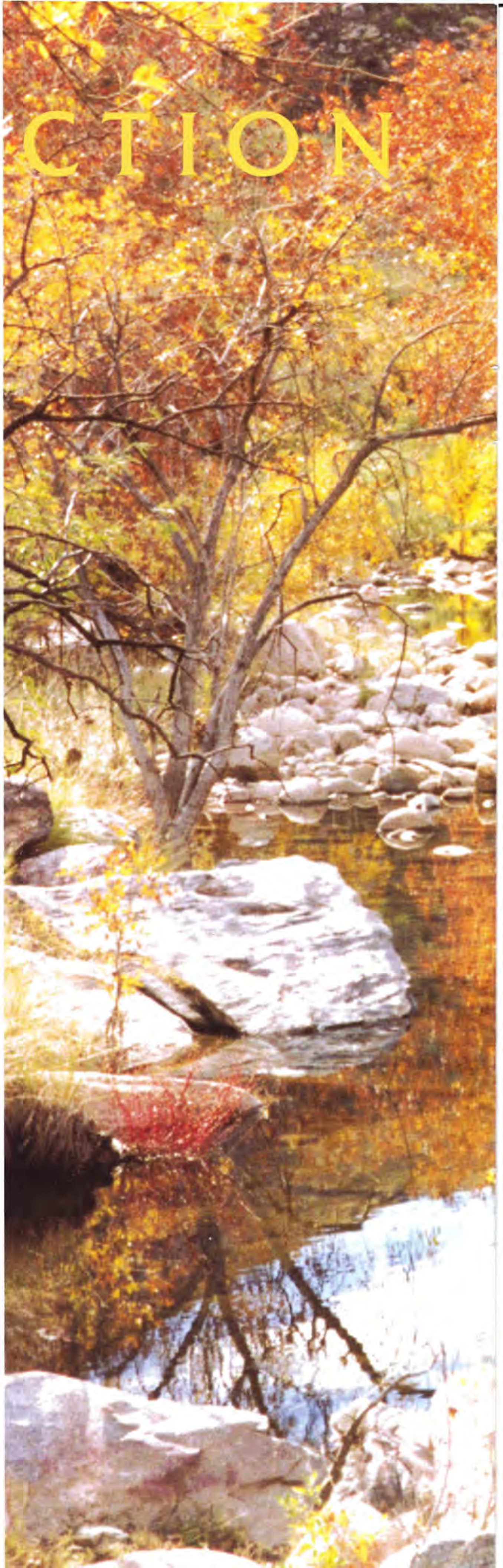
Mr. John Birmingham deserves special thanks for the many hours he devoted to designing this publication.

Dr. John Dohrenwend graciously granted permission to use his satellite image in this publication. Poster-sized satellite image maps (1:100,000 scale) of the Santa Catalina Mountains and of the Tucson Basin can be ordered from John Dohrenwend, P.O. Box 141, Teasdale, UT 84773; Phone (435) 425-3118; E-mail: Dohrenwend@rkymtnhi.com.

This publication would not have been possible without the professional support of Dr. Larry D. Fellows, Director of the Arizona Geological Survey.

This publication is dedicated to Andrew William Amann, Jr. Andy co-authored *Ice Age Mammals of the San Pedro River Valley, Southeastern Arizona* and assisted in the publication of other titles in the Down-to-Earth series. We are indebted to Andy for his contribution to the success of this series.

# INTRODUCTION



Upper Sabino Canyon Road, also known as the Sabino Canyon Shuttle Route, and the Catalina Highway to Mount Lemmon offer a variety of spectacular geologic features. Because of the relatively sparse vegetation in the lower part of the range, most of these features are easy to recognize and photograph.

Some of these features are common throughout this southern part of the Santa Catalina Mountains. Others occur in many other parts of the American Southwest.

This booklet is your field guide to the geology of this spectacular mountain landscape. All of the geologic features described in the text can be reached by short walks from the Sabino Canyon Shuttle Route or the Catalina Highway. This book is written for the visitor who has an interest in geology, but who may not have had formal training in the subject. It may also help assure that the visiting geologist does not overlook some of the features described.

To set the stage, I have briefly described the area's geologic setting and history. In the following pages, emphasis is given to description of geologic features that are common in this landscape. Precise directions to each feature are provided in the text. Three features – gneiss, sill, and tinajas – are discussed in both the Sabino Canyon and the Catalina Highway parts of the guidebook.

Locations of the geologic features and access roads and trails are shown on Figures A and B. The Sabino Canyon Shuttle Route is not open to private vehicles; transportation is available by shuttle bus should you not have the time to hike the entire road. The Catalina Highway, a paved mountain road with curves and steep grades, should be driven with care. Numerous turnouts make it easy for one to enjoy the drive at a leisurely pace.

Another purpose of the field guide is to provide the reader with an understanding of the dynamic processes that have shaped this exceptional landscape. You will encounter many of the features discussed in the text again and again as you continue to explore the Southwest. I hope that your experience in Sabino Canyon and along the Catalina Highway will enhance the pleasure of those explorations.

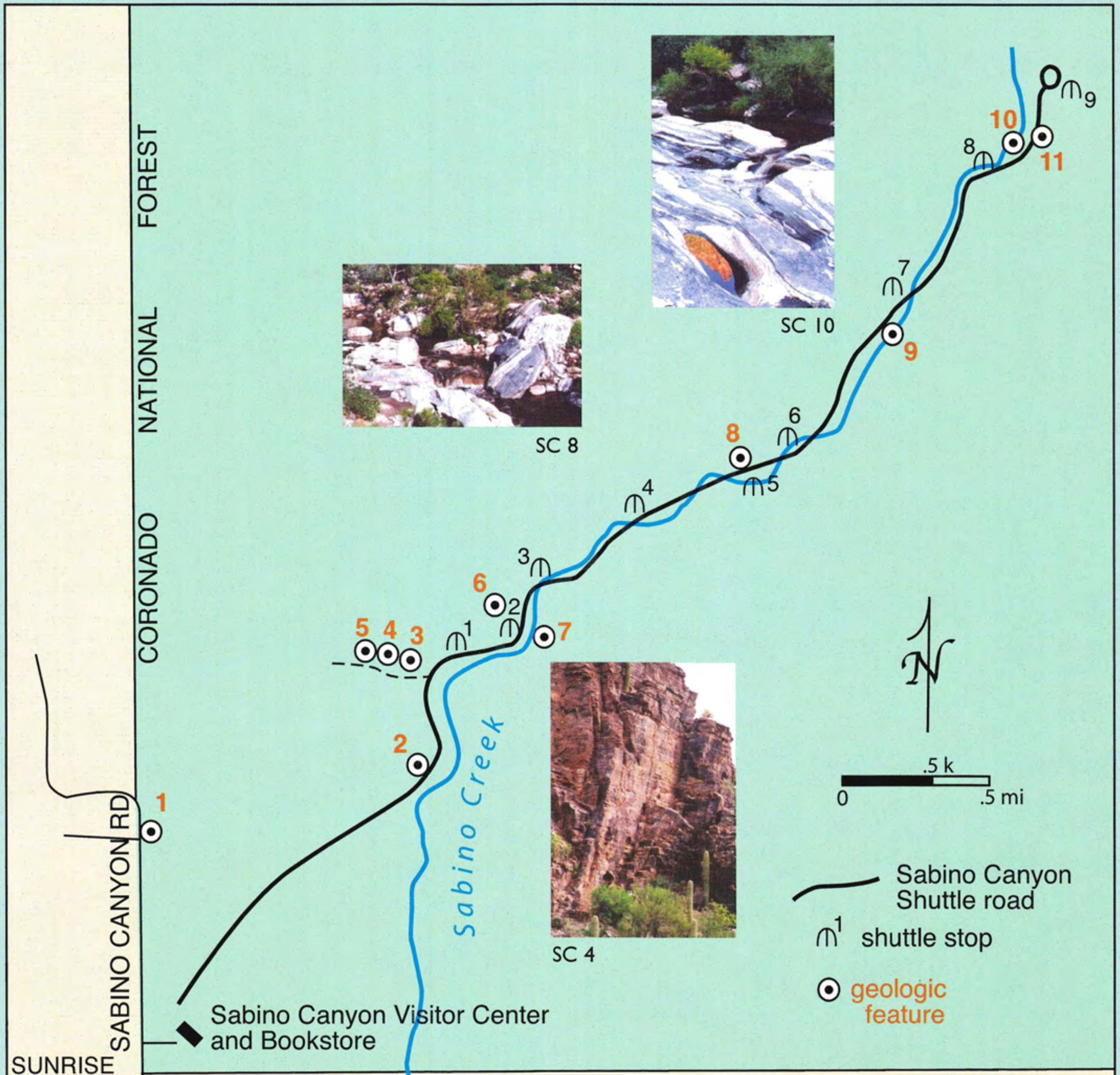


**Figure A.** Geologic Features along Sabino Canyon Shuttle Route (SC).

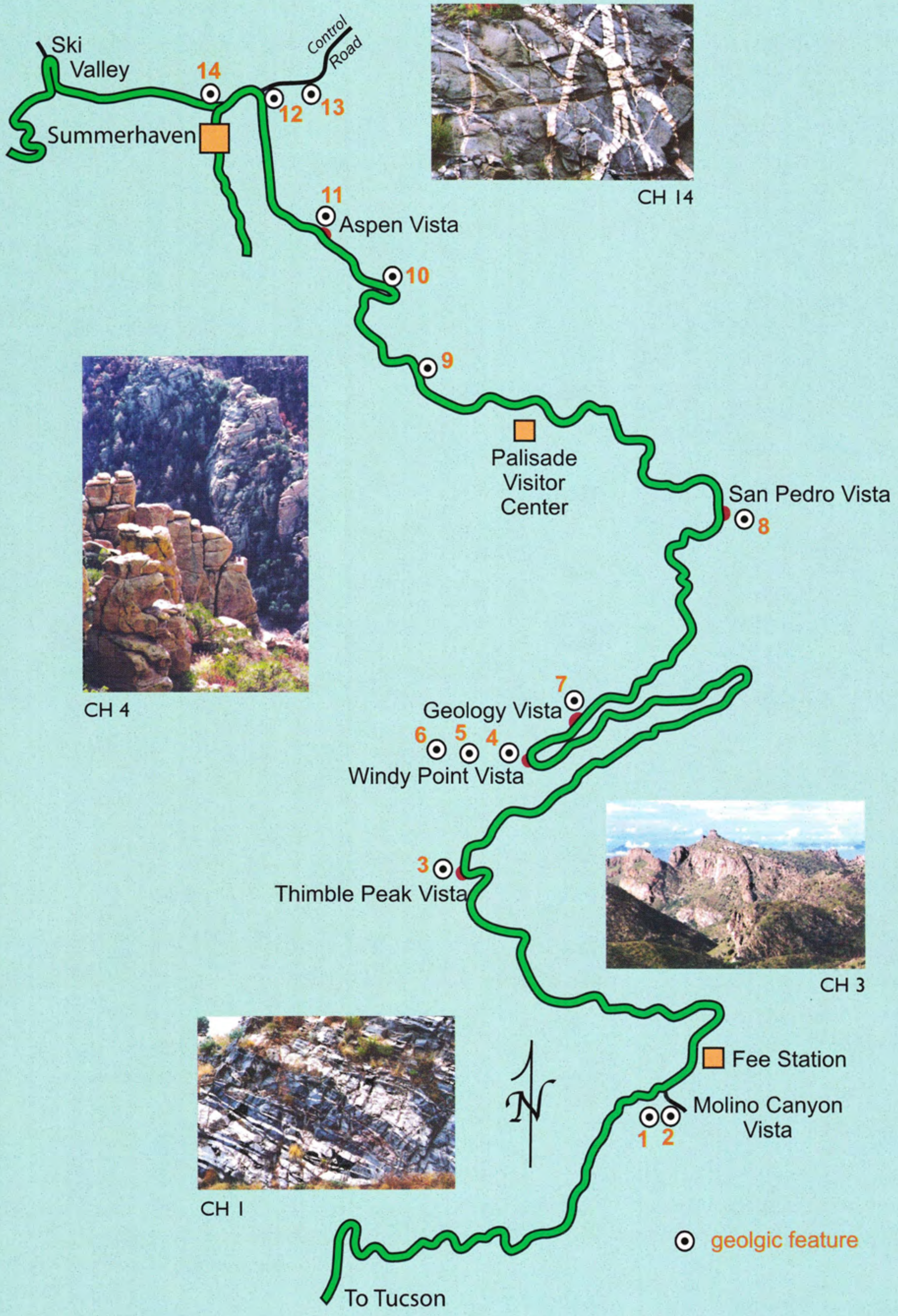


**Figure B.** Geologic Features along the Catalina Highway (CH).

**Figure C.** Santa Catalina Mountains showing the distinctive dome-shaped profile of the range.

# GENERAL GEOLOGY OF THE SANTA CATALINA MOUNTAINS

The Santa Catalina Mountains are, in large part, a highly eroded uplift of bedrock, called a *metamorphic core complex*. Although running water has cut deep canyons into the mountain range, much of its original arched shape is preserved (Figure C). The Santa Catalina, Rincon, and Tortolita Mountains are among more than two dozen metamorphic core complexes that extend from northern Mexico into southern Canada (Figure D). They formed as a result of the extension and thinning of the Earth's crust in western North America that began about 35 million years ago.

In some parts of the continent this stretching and thinning caused crustal rocks to pull apart and break along low angle shear zones (usually less than 30 degrees) called *detachment faults*. The Catalina fault, the detachment fault associated with the uplift of the Santa Catalina Mountains, parallels the southern margin of the range but is covered by sediment for most of its length (Figures E and F) and is not exposed in Sabino Canyon or along the Catalina Highway.

The Catalina fault began to form about 35 million years ago at a depth of about 6 to 8 mi (10 to 13 km). Rocks below the fault were moved toward the east-northeast 16 to 19 mi (25 to 30 km) and came closer to the Earth's surface as rocks above the fault were displaced toward the southwest.

This movement deformed rocks above and below the shear zone. Those rocks far below the fault, mainly Wilderness Suite and Oracle granites, were so hot that they flowed like a plastic. The mineral particles in these rocks, especially quartz, smeared plastically. Other minerals in the rock, particularly feldspar, broke into pieces or had their corners broken off to produce lenticular crystals called *augen* ("eyes" in German). This deformation of the granites resulted in a new rock type, *gneiss* (pronounced "nice"). Rocks above the fault were cooler and deformed in a brittle manner.

As the rocks below the detachment fault moved slowly toward the surface, they were domed up in response to the removal of the weight of overlying rocks.

A second period of extension occurred after detachment faulting and core complex uplift. This extension caused the crust to break into blocks separated by new, higher-angle faults. These crustal blocks were uplifted to form many of the mountain ranges in southern Arizona. Other blocks subsided as much as 2 to perhaps 4 kilometers (1.25 to 2.5 miles) to form many of the basins that are beneath the valleys. During this period of crustal deformation the Basin and Range geologic province formed, which extends from Oregon to northern Mexico (Figure D).

Downward-cutting streams encountered the rocks of the rising metamorphic core complex that eventually became the Santa Catalina Mountains. Running water stripped away much of the more easily eroded rock from the crest of the once-buried dome. Continued erosion by streams caused Sabino, Bear, Molino, and other deep canyons to be incised into the hard gneiss and granite of the Catalina forerange (Figure E).

As particles of the weathered and eroded rock were flushed down Sabino, Bear, and other canyons during flash floods they were reduced in size as they collided with each other. Boulders and cobbles, tumbled by torrential flows, cut canyon floors progressively deeper.

This coarse sediment accumulated along the southern margin of the mountain front as fan-shaped deposits called *alluvial fans*. Since their formation, these fans have been highly eroded by running water. The high fan remnants south and west of the Sabino Canyon Visitor Center are popular building sites for homes with a view (Figure F).

Sand, silt, and clay particles were washed farther from the canyons and filled the Tucson basin.

**Figure D.** Distribution of metamorphic core complexes in western North America (modified from Crittenden Jr., Coney, and Davis, 1980).

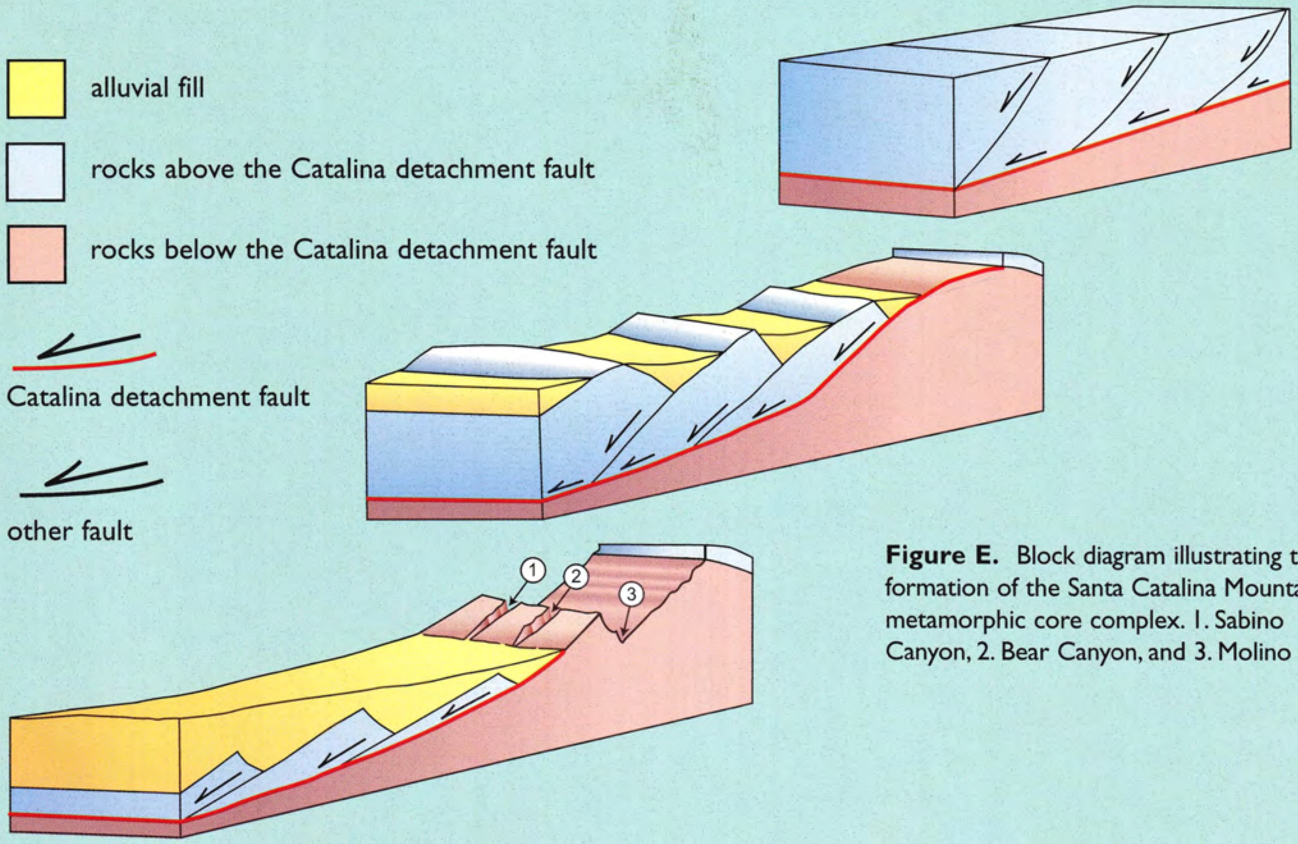


**Figure E.** Block diagram illustrating the formation of the Santa Catalina Mountains metamorphic core complex. 1. Sabino Canyon, 2. Bear Canyon, and 3. Molino Basin.

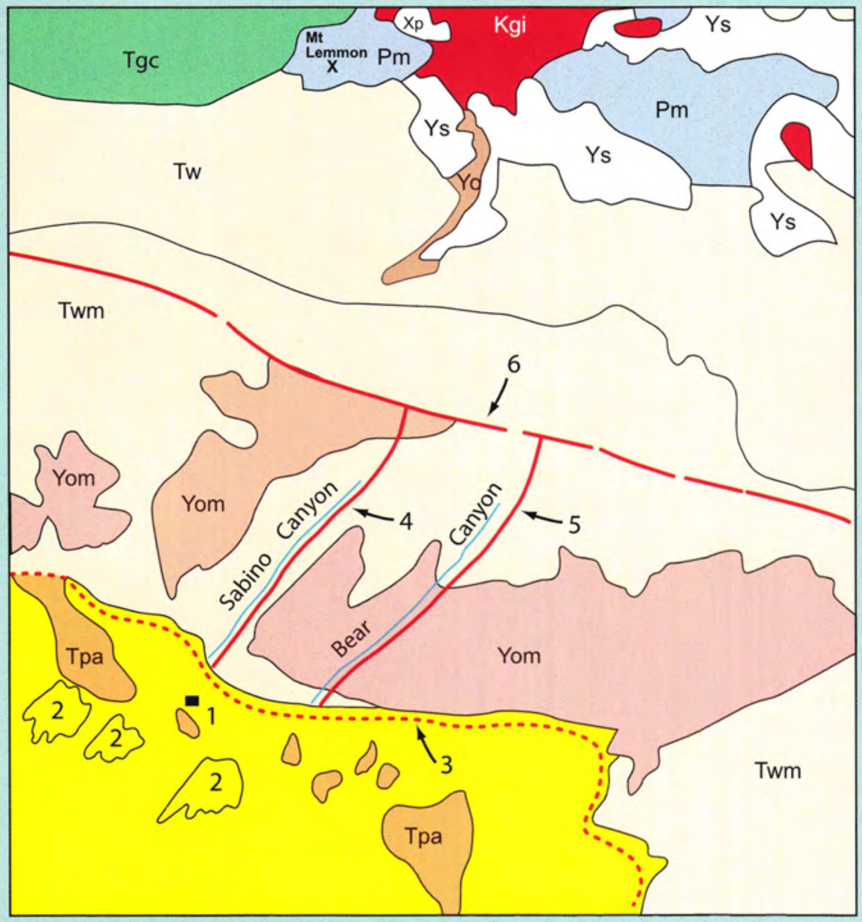


**Figure F**. Geology of the central southern Santa Catalina Mountains (after Dickinson, 1992). 1. Sabino Canyon Visitor Center, 2. alluvial fan remnants, 3. Catalina detachment fault, 4. Sabino Canyon fault, 5. Bear Canyon fault, 6. Romero Pass fault

Qal=alluvial fill
Tpa=Pantano Formation
Tw=Wilderness Suite Granite
Twm=gneiss (mylonitic Wilderness Suite Granite)
Yom=gneiss (mylonitic Oracle Granite)
Yo=Oracle Granite
Ys=Apache Group and Troy Quartzite
Pm=metamorphic strata
Xp=Pinal Schist
Kgl=Leatherwood Granodiorite
Tgc=Catalina Granite


BC
SC

# GENERAL GEOLOGY OF SABINO CANYON

Sabino and Bear Canyons were cut by running water that eroded the resistant gneiss and granite that forms the southern margin or forerange of the Santa Catalina Mountains (Figure G). The gneiss formed about 25 to 35 million years ago from the deformation of two kinds of rock: the 1.4-billion-year-old Oracle granite and granite and pegmatite that were injected into it as sills about 50 million years ago.

The granite sills (slab-like injections) are particularly resistant to erosion because they contain much quartz and feldspar and little mica. The Seven Falls sill, for example, is a prominent ledge from which water plunges during times of high stream flow. The Gibbon Mountain sill forms the high cliffs that rim the upper part of Sabino Canyon. Thimble Peak, a prominent pinnacle that towers above the canyon, is an erosional remnant of the Thimble Peak sill. This gneiss and granite formed a dome miles below the Earth's surface about 25 million years ago. Faulting and down cutting by streams eventually caused the dome to be eroded and uncovered. Running water stripped away the more easily eroded rocks from the crest of the dome and cut deep canyons into the harder and more resistant gneiss. The courses of these canyons were largely determined by faults in the bedrock.

Sabino Creek and Bear Creek followed the shattered rock of the Sabino Canyon and Bear Canyon faults to cut their canyons through the Santa Catalina forerange (Figure H). Flash floods, working in concert with landslides and rockfalls, continue to deepen and widen the canyons.

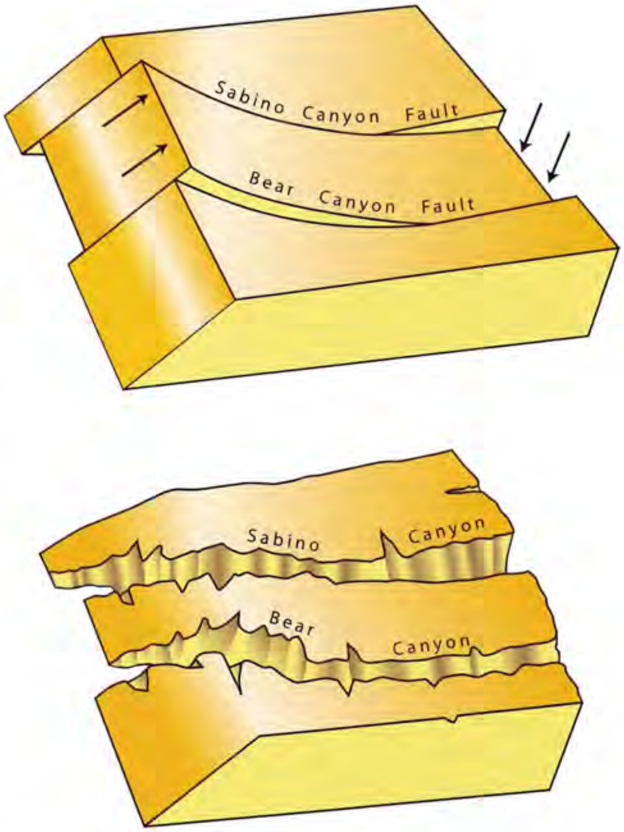


**Figure H.** Block diagram illustrating the formation of Sabino and Bear Canyons (modified from Force, 1997).

Opposite: **Figure G.** Satellite image of the Sabino Canyon (SC) and Bear Canyon (BC) area.

# GEOLOGIC FEATURES
# ALONG
# UPPER SABINO CANYON ROAD
## (SABINO CANYON SHUTTLE ROUTE, SC)

# FEATURE SC 1 ▶ TRIANGULAR DOME FACETS

**Figure SC 1.** Triangular dome facets (A) along the southern margin of the Santa Catalina Mountains.

**Location:** This feature is best viewed from near the junction of Sabino Canyon Road and East Sabino Crest Place, about one-half mile north of the entrance to Sabino Canyon Recreation Area.

Triangular-shaped, convex rock faces (Figure SC 1, A) separated by V-shaped canyon mouths form the southern margin of the Santa Catalina Mountains. These landforms, called *triangular dome facets*, retain the original arched form of the bedrock when it was first being exposed to weathering and erosion at the Earth's surface. They are hallmark features of metamorphic core complex mountains (see General Geology of the southern Santa Catalina Mountains section).

About 25 million years ago, the crust in this part of the continent was stretched, thinned, and broken along low angle fractures, called detachment faults. This movement allowed masses of granite to rise and dome up the crustal rocks to form metamorphic core complexes, as mountains with this structure are called.

Streams that flowed down the slopes of the newly exposed dome were quickly established. These drainages cut down through more easily eroded rock on the crest of the dome and incised deep canyons in the underlying, erosion-resistant granite and gneiss (Feature SC 3). The resulting series of aligned, triangular-shaped rock faces between the mouths of Sabino, Bear, and other canyons make a bold and distinctive southern front for the Santa Catalina Mountains.

**Location:** Hike the Shuttle Route about 0.8 mi (4,200 ft, 1300 m) to where the Bluff Trail #51 intersects on the right. The Sabino Canyon fault is exposed in roadcuts along the west side of the Shuttle Route for a distance of about 600 ft (190 m) opposite this trail intersection (230 ft [70 m] to the south and 370 ft [113 m] to the north of the intersection).

The bedrock along Sabino Canyon has been crushed and pulverized by a fault or a narrow zone of closely spaced faults. A fault is a fracture in the brittle rocks of the Earth's crust along which movement has occurred.

Slippage along the Sabino Canyon fault generated tremendous friction that produced a zone of powdered (*fault gouge*) and crushed rock (*breccia*, pronounced "bretch-a") that can be traced for miles. Groundwater containing dissolved iron circulated through the breccia and cemented the crushed rock fragments. The reddish color of the breccia zone is due to the rusting (oxidation) of these minute quantities of iron. The fault is not active.

The gently curved course of Sabino Canyon is due to weathering and erosion of the Sabino Canyon fault. Sabino Creek followed the shattered rock along the fault and cut a deep canyon into the hard, erosion-resistant gneiss of the Santa Catalina forerange (Figure SC 2.1).

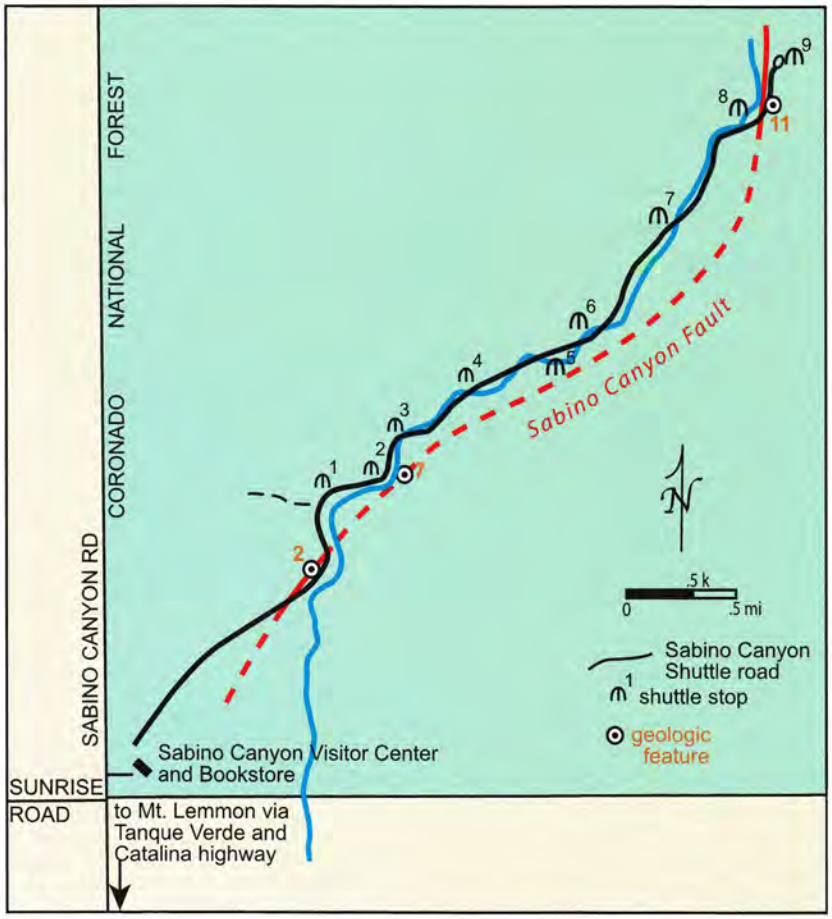


**Figure SC 2.1.** The Sabino Canyon fault is shown as the dashed red line. Features 2, 7, and 11 are related aspects of the fault.

To best view the fault walk about 230 ft (70 m) south of where the Bluff Trail #51 intersects the Shuttle Route and look at Figures SC 2.2 and 2.3 to orient yourself. The fault breccia (Figure SC 2.4) is the reddish-colored rock, up to a foot thick, that is exposed near the base of the roadcut intermittently for about 600 ft (190 m) northward from where the photograph in Figure SC 2.3 was taken.

The fault continues northward across Sabino Creek, cuts the small hill just to the north of Mile Marker 1 (Figure SC 2.5), and continues northward beyond the end of the Shuttle Route. The fault and associated features are also described as features SC 7 and 11.

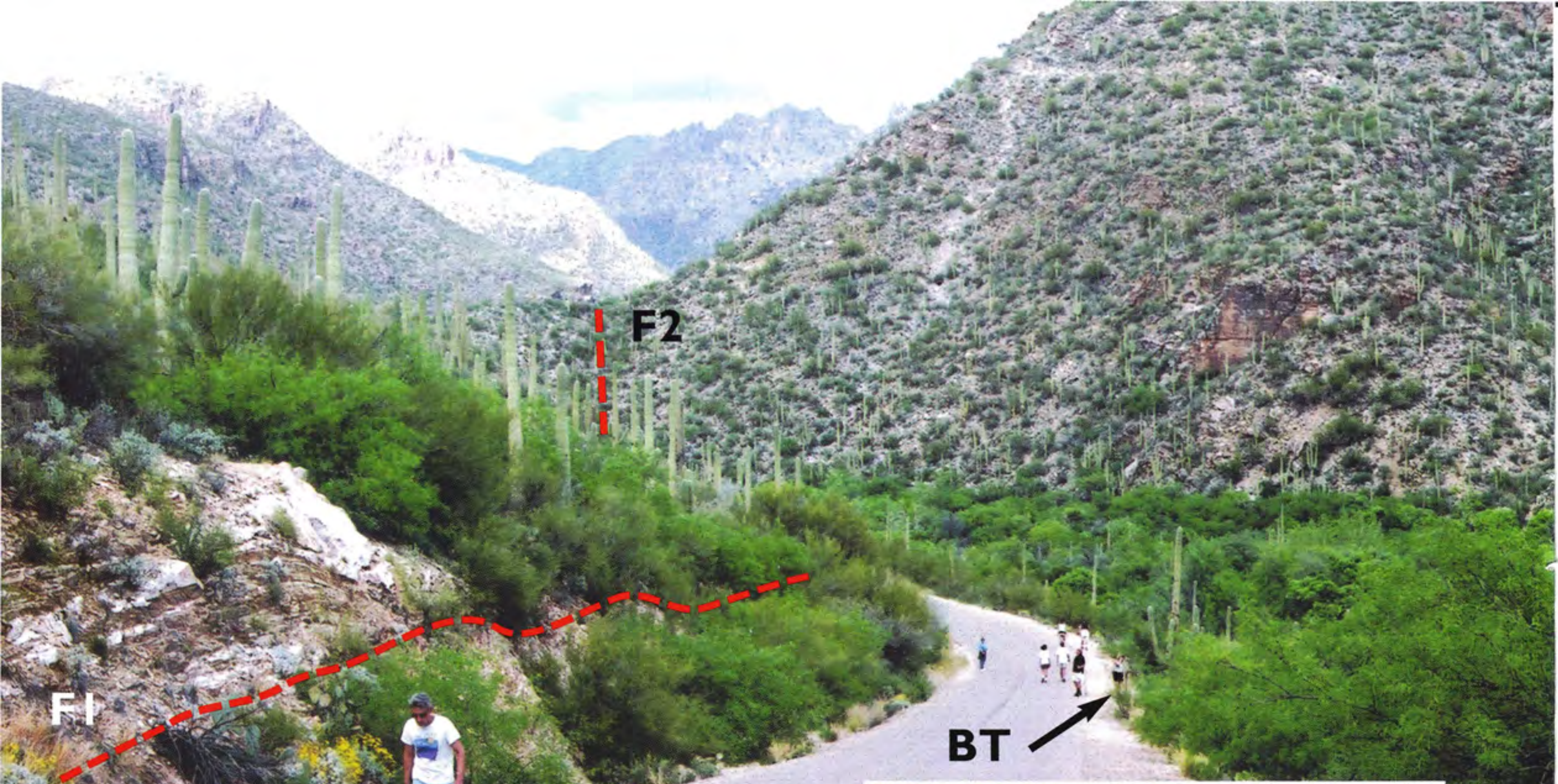


**Figure SC 2.2.** As the Shuttle Route begins to descend into Sabino Canyon the fault (F 1) is on the left (west) side of the road. The fault continues northward and cuts the small hill in the distance (F 2). The intersection with the Bluff Trail is shown as BT.

**Figure SC 2.4.** Fault breccia. This photograph was taken about 370 ft (113 m) to the north from where the Bluff Trail intersects the shuttle route.

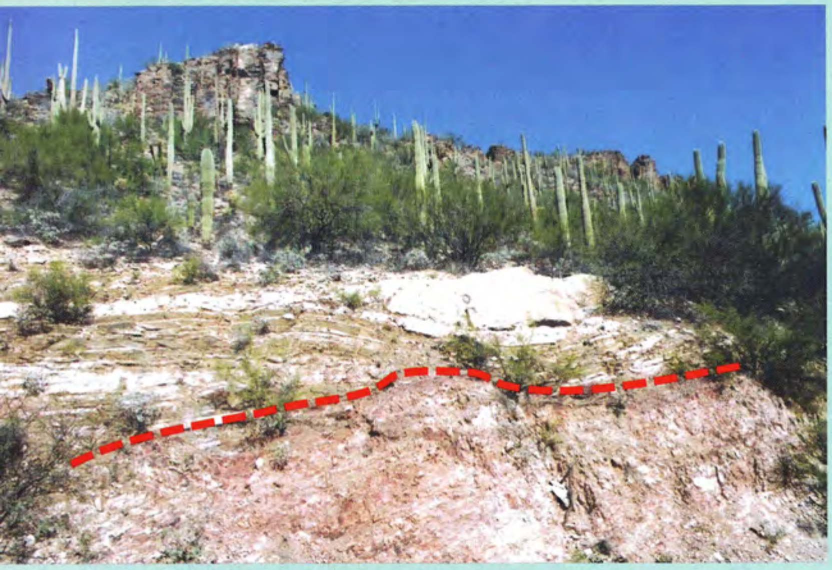


**Figure SC 2.3.** Fault along the west side of the shuttle road at the south end of Sabino Canyon. This photograph was taken about 230 ft (70 m) south from where the Bluff Trail intersects the shuttle route.

**Figure SC 2.5** Small hill cut by the Sabino Canyon fault just north of Mile Marker 1.

**Location:** Follow the Sabino Canyon Shuttle Route to Rattlesnake Canyon Trail (#50). The trail intersects the Shuttle Road from the left (west), a short distance down the road (northwest) from Mile Marker 1, and just south of Shuttle Stop 1. Walk the trail about 35 yd (about 35 m). The gneiss is exposed in the cliff on the north (right) side of the trail.

The color-banded rock in Figure SC 3 is *gneiss*, the most common rock type in the southern Santa Catalina Mountains. Because gneiss has a laminated texture, like that of innumerable, thin layers, the landscape has an angular, ledgy nature.

Gneiss is a metamorphic rock. Intense heat and pressure caused minerals in the parent rock to recrystallize (metamorphose) to form the gneiss. This gneiss had two parent rocks: the Precambrian-age (1.4 billion years ago) Oracle granite and the Eocene-age (50 million years ago) Wilderness Suite granite. These granites formed from great molten masses of rock that cooled slowly miles below the Earth's surface.

**Figure SC 3.** Gneiss at the intersection of Rattlesnake Canyon with Sabino Canyon. This view is toward the northwest from near Mile Marker 1.

The minerals feldspar, quartz, and mica crystallized as the granite slowly cooled. The Wilderness Suite granite is somewhat unusual in that it also contains crystals of red garnet. Between 35 and 20 million years ago, when these granites were at a depth of about 7 to 10 mi (10-15 km), the Earth's crust in this region was stretched and sheared in a southwest-northeast direction. The intense pressure and heat that accompanied this stretching deformed part of the deeply buried Oracle and Wilderness Suite granites into the gneiss that is exposed in the southern part, the forerange, of the Santa Catalina Mountains.

At temperatures of 600°F (350°C), the quartz crystals in the granites behaved like hot, soft plastic and smeared in long ribbons parallel to the direction of crustal stretching. The feldspar crystals, which are more brittle at this temperature, were rolled, crushed, and spread out – also in the direction of extension. These long, aligned streaks of deformed minerals give the gneiss its unique texture. The dark-colored bands are interpreted to be deformed Oracle granite; those of lighter colors once may have been Wilderness Suite granite.

Locally the gneiss is stained red and yellow by iron oxides. This is particularly common along fractures, where hot fluids chemically altered the rock and deposited minute quantities of hematite and limonite.

# FEATURE SC 4 ▶ JOINTS

**Figure SC 4.** Joint in gneiss (A) where Rattlesnake Canyon intersects Sabino Canyon. The light colored area is a joint face.

**Location:** Follow the Sabino Canyon Shuttle Route to Rattlesnake Canyon Trail (#50). The trail intersects the road from the left (west), a short distance south of Shuttle Stop 1. Walk the trail about 35 yd (about 35 m). The joints are developed in the cliff on the north (right) side of the trail.

The cracks in the rock in this cliff face are *joints* (Figure SC 4, A). Most of these joints are the result of stress associated with faulting, folding, and other movements in the Earth's crust after the original granite was converted to gneiss. Some joints, called master joints, can be traced for miles across the landscape.

Joints are pathways along which water can penetrate the bedrock and cause destructive chemical and physical weathering processes. Water from rain and snowmelt seeps into joints and freezes during winter nights. The resulting expansion of the ice exerts sufficient pressure to break mineral grains and widen joint walls. Plant roots also may enter and wedge open the joints. Accumulated soil in the joints acts as a sponge that keeps slightly acidic groundwater in contact with joint walls, and enables chemical weathering processes to decompose the rock more rapidly.

The weathering and erosion of intersecting joint sets over hundreds of thousands of years have had a profound influence on today's topography. Joints, together with faults, determine the courses of Sabino, Bear, Molino and other major canyons, as well as the form of intricate, small-scale features such as the pinnacles at Windy Point (Feature CH 4, Catalina Highway section).

**Location:** Same location as Feature SC 4.

The tan- to brown-colored substance on the surface of the gneiss (Figure SC 5.1) is *rock varnish*. This mineral patina masks the true color of the rock, which is white and black. Rock varnish develops best on rocks that have moderately rough surfaces. Basalt, sandstone, and many metamorphic rocks are commonly well varnished, whereas siltstone and shale disintegrate too rapidly to retain such a coating.

Rock varnish consists of thin layers (typically less than one hundredth of an in [0.25 mm]; Figure SC 5.2) of clay minerals (illite, smectite, and kaolinite) stained by high concentrations of iron and manganese oxides. The clay minerals settle as dust from the atmosphere. Manganese, also derived from windborne dust and rain, produces a black to dark-brown coloration on surfaces exposed to air.

Micro-colonies of lichens and bacteria inhabit the varnish and gain energy by oxidizing the manganese. They anchor themselves to rock surfaces with the clay particles, which provide protection against extremes in temperature and humidity. In the process, the manganese becomes attached firmly to and darkens the clay. Each time the rock surface is wetted by rain, more manganese and clay are added to sustain the slowly growing colony. Such colonies thrive where the rock acidity is neutral and the surface is so nutrient poor that competing colonies of lichens and mosses cannot survive.

**Figure SC 5.1.** The gneiss is coated with a dark-colored substance called rock varnish.

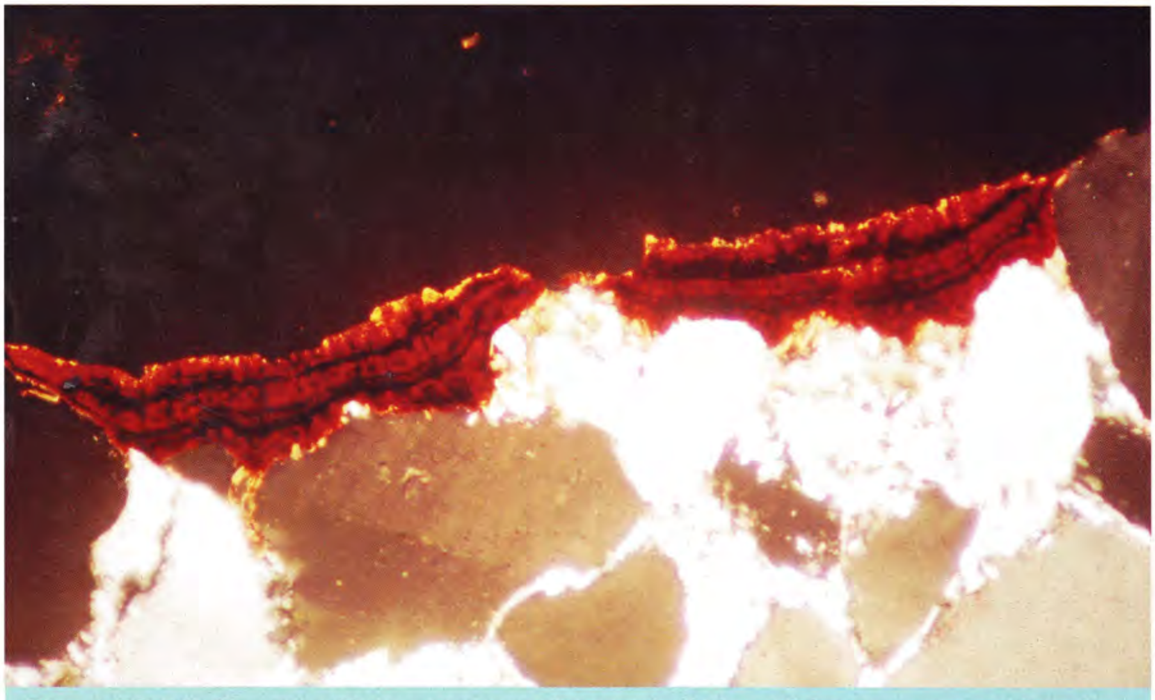


**Figure SC 5.2.** Transmitted light microscope photograph of layers of clay, manganese and iron that form rock varnish. Photograph was provided by Dr. Ron Dorn, Arizona State University.

Scientists are unable to use rock varnish as a precise dating tool, even though older surfaces tend to be more heavily varnished and darker than younger surfaces. The rate at which rock varnish forms is not constant, because it is affected by many variables, such as climatic change, wind abrasion, biological competition, and abundance of manganese. Some researchers believe that the clay and manganese content of rock varnish reflects past climatic conditions.

Well-varnished surfaces have a dull luster that causes entire hillsides to glisten in intense desert sunlight. This mineral coating gives the landscape its warm tones of brown and ebony that commonly mask colorful bedrock below. All of Earth's deserts have varnished rocks, but in the Southwest these surfaces provoke even greater interest because of their archaeological importance. In innumerable locations prehistoric Indians pecked petroglyphs (rock drawings) through the mineral skin to the fresh rock below. Today these symbols are being re-varnished as the process continues.

# ROCKFALLS AND LANDSLIDE DEBRIS ◀ FEATURE SC 6

**Figure SC 6.** Rock debris from rockfalls or a landslide.

**Location:** Shuttle Stop 2. The rock debris covers the hill slope on the west side of Sabino Creek.

The jumbles of boulders on the slope above the rest rooms either dislodged one at a time from the cliff above or were deposited there by a landslide. *Rockfalls* occur when great slabs and blocks of bedrock separate along natural cracks (joints) from cliff faces and fall to the lower slopes of the canyon. The slabs are usually broken into boulder-sized fragments by the impact. Recent rockfalls expose areas of light-colored, less weathered rock that contrast with the dark mineral oxide staining on the rest of the cliff surface.

*Landslides* result when an entire section of the canyon wall fails, usually because the rock has become saturated with moisture from heavy rains or snowmelt. Wildfires contribute to landslides by destroying vegetative cover that stabilizes loose rock debris on steep slopes.

Rock debris mantles the slopes of Sabino Canyon for most of its extent. Some of this debris is from individual rockfalls and some has moved downslope by landslides. Although landslides and rockfalls continue to occur, some of this rock material may have accumulated during the wetter climatic cycles of the last Ice Age.

Rockfalls and landslides play a major role in canyon widening. The rock debris eventually reaches the streambed where, overtime, it is broken into smaller fragments and flushed from the canyon by flash floods.

# FEATURE SC 7 ▸ FAULT SURFACE AND FACETED SPUR

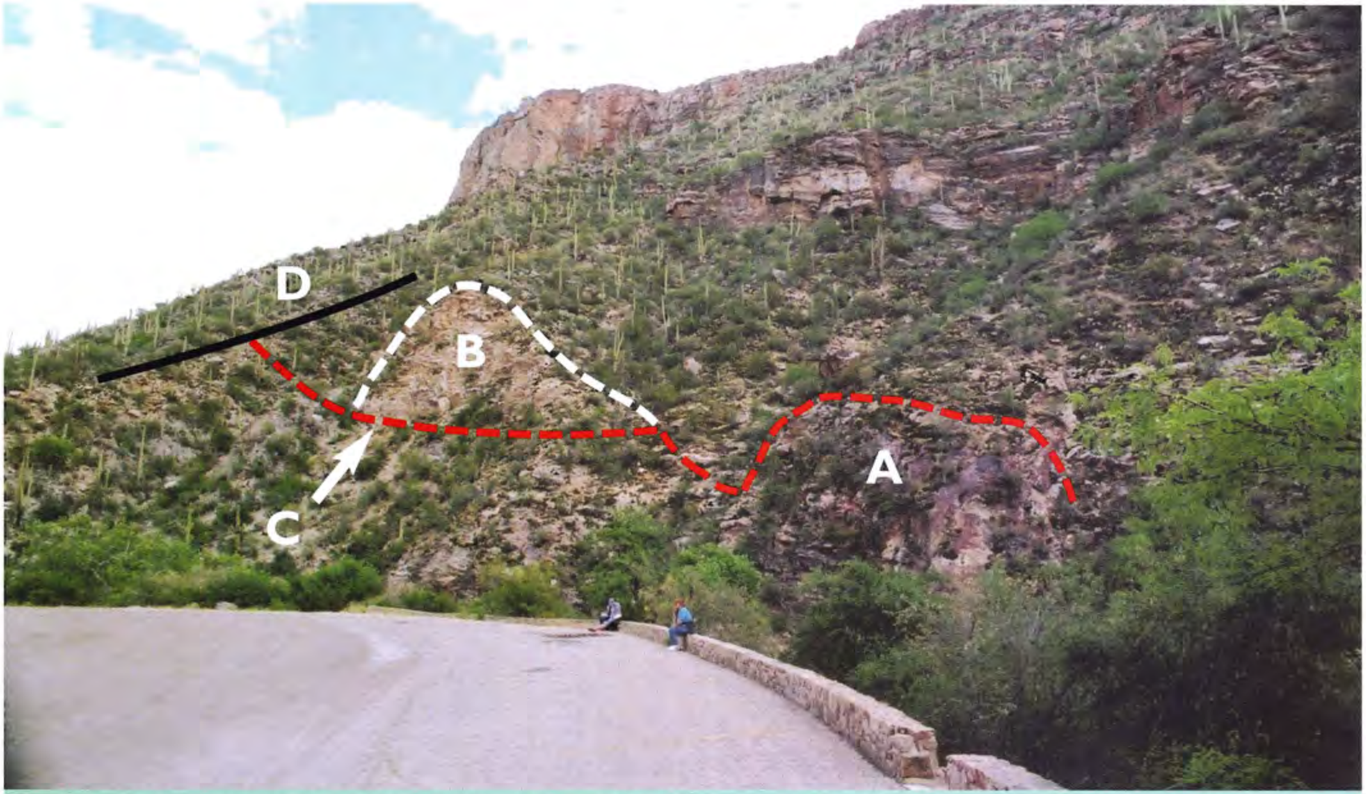


**Figure SC 7.1.** Fault surface (A) and a faceted spur (B) adjacent to the fault (C) on the east side of Sabino Creek at Shuttle Stop 2. At the north end of the faceted spur the fault is overlain by rock debris (D).

**Location:** Shuttle Stop 2, on east side of Sabino Creek.

The fault that was described as Feature SC 2 is clearly exposed on the east side of Sabino Creek at Shuttle Stop 2. Rocks on both sides of the fault were ground smooth, almost polished, by friction as movement occurred along the fault surface. A portion of the actual fault surface, stained dark maroon by hematite, is visible on the slope above Sabino Creek (Figure SC 7.1, A). Figure SC 7.2 is a close-up view of the fault surface.

The fault extends northward (toward the left) into the hillslope (Figure SC 7.1, B). The triangular-shaped rock outcrop, adjacent to the fault, that has no vegetation on it is called a *faceted spur* (Figure SC 7.1, C). Just to the north of the faceted spur a layer of rock debris (D) from the high cliffs to the east covers the fault.

**Figure SC 7.2.** Closer view of the fault surface (arrow).

# STREAM DEPOSITS ◀ FEATURE SC 8

**Location:** Shuttle Stop 5. Walk into the streambed at the bridge.

Sabino Creek acts as a geological conveyor belt, moving rock fragments from the floor of Sabino Canyon to the Tucson Basin. Most of this rock material is flushed from the canyon by torrential flash floods during the summer thunderstorm season.

The rock fragments in the stream channel are boulders, cobbles, pebbles, and sand that have been rounded by tumbling during floods (Figures SC 8.1 and 8.2). In the high, upstream portions of the channel the fragments are larger and more angular because they have not been subjected to as many shattering collisions with other rocks that occur during transport by flash floods. Beyond the mouth of the canyon are jumbles of boulders that have been rafted and flushed along by mudflows. Subsequent flows of lesser volume have washed away the small rock fragments, leaving the boulder deposits as testimony of the power of flowing mud.

By the time they reach the Tucson Basin, farther from the mountain front, rock fragments being transported have been reduced to rounded pebble- and sand-sized particles because of collisions and tumbling. Also, because of more gentle slopes in the basin, streams do not have the power to transport large rock fragments. In the lowest part of the basin, sand and mud are the most common deposits.

The flash-flood transport of loose rock fed into streams by landslides and rockfalls (Feature SC 6) is the principal process for wearing down mountain ranges and filling adjacent basins with sediment.

**Figure SC 8.1.** Coarse and fine stream deposits in Sabino Creek. The dark color in the sand is ash that was transported by the stream after extensive forest fires higher in the mountains the previous year.

**Figure SC 8.2.** Boulders in Sabino Creek. The boulders are composed of gneiss.

# FEATURE SC 9 ▶ SILL

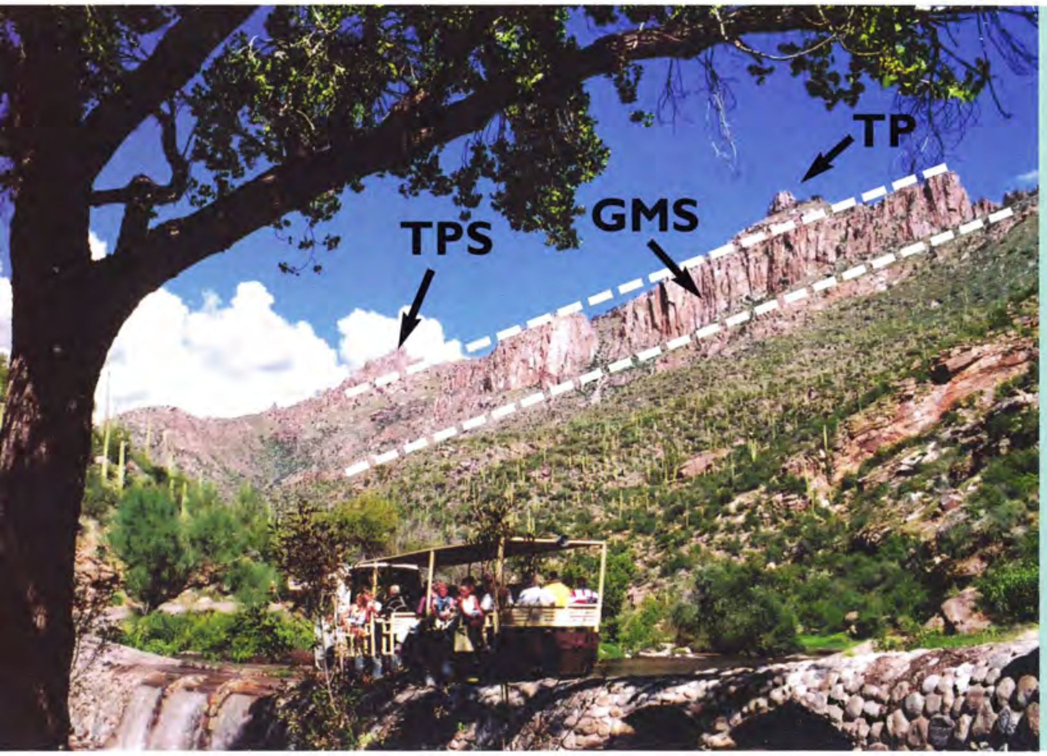


**Figure SC 9.1.** Thimble Peak (TP) and the Gibbon Mountain sill (GMS). Thimble Peak is an erosional remnant of the Thimble Peak sill (TPS).

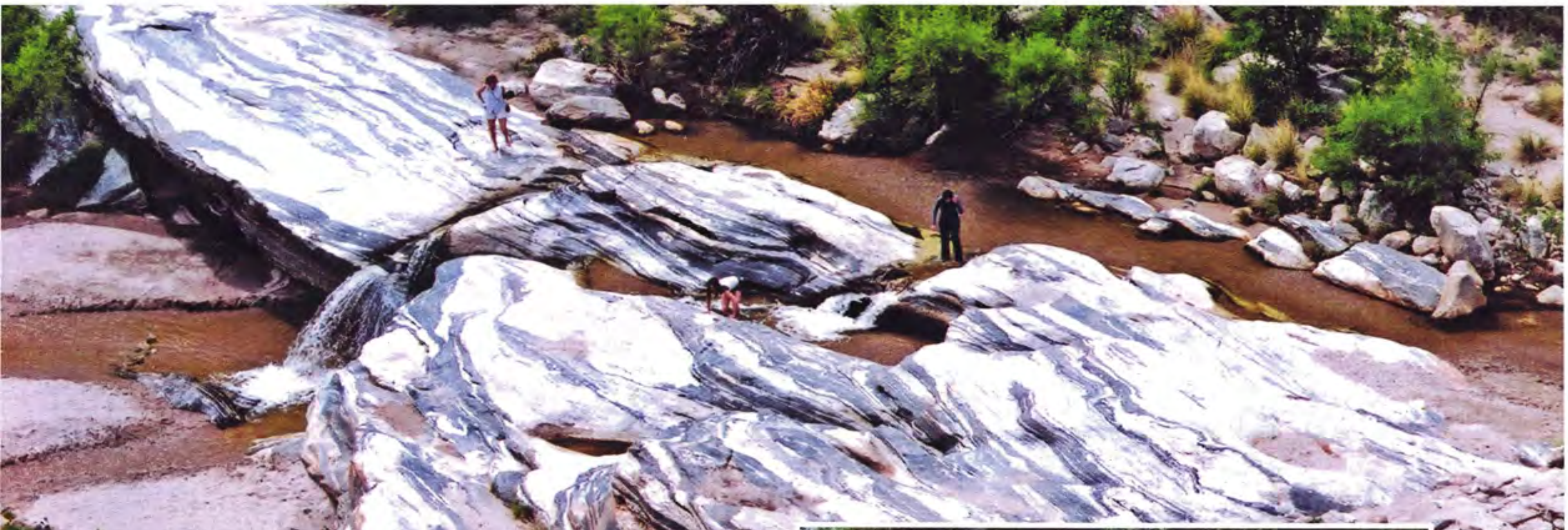
**Location:** Between Shuttle Stops 6 and 7. Thimble Peak is the prominent feature at the crest of the ridge on the east side of Sabino Canyon.

Thimble Peak (Figures SC 9.1 and 9.2) is an erosional remnant of a thick, layer-shaped intrusion of granite called a *sill.* About 50 million years ago (Eocene time), when this granite was hot and molten, it was injected into the 1.4-billion-year-old Oracle granite – a gigantic mass of once-molten rock that underlies much of this part of Arizona. The sill cooled at great depth, was uplifted, and has been exposed by erosion.

Sills are tabular injections of molten rock (magma) that wedge open and penetrate layers and other planes of weakness in the host rock. They range in thickness from a fraction of an inch to thousands of feet and can be miles in length. This sill, called the Thimble Peak sill, reaches a thickness of 2,600 ft (800 m) to the north where it is fully exposed. The Gibbon Mountain sill is immediately beneath Thimble Peak. This and other sills make up much of the rock in this part of the southern Santa Catalina Mountains.

Sills are of considerable geologic importance. Multiple injections of sills can greatly thicken the local crustal rocks, as they do in the Santa Catalina Mountains. In addition, sills that are harder than the surrounding host rock commonly erode to form high cliffs, such as those below Thimble Peak. In some areas, the interaction of the sill magma with the adjacent host rock produces precious and industrial metal deposits.

**Figure SC 9.2.** Closer view of Thimble Peak (TP) and the Gibbon Mountain (GMS) sill.



Above: **Figure SC 10.1.** A hard layer of gneiss is present beneath Sabino Creek at Shuttle Stop 8.

**Location:** Shuttle Stop 8. Walk up Sabino Creek for about 100 yd (about 100 m).

A hard layer of gneiss is exposed along Sabino Creek (Figure SC 10.1). The depression or rock basin that holds water in Figure SC 10.2 is a *tinaja* (pronounced tee-na'-ha), the Spanish word for a large earthen water jar fired so that water will seep to the vessel's surface and keep its contents cool by evaporation. Tinajas or rock tanks, as they are called in English, are best formed in the bedrock channels of steep canyons cut into desert mountain ranges.

Boulders, cobbles, and pebbles tumbled by swiftly flowing water during flash floods act as cutting tools that gouge out depressions in the underlying bedrock. The upstream sides of these enlarging depressions, which bear the full impact of the moving rock debris, are consequently deeper than the downstream sides, which are breached by outlet channels. Because of this asymmetrical shape, tinajas are flushed clear of organic and rock debris by flash floods and filled with water by the slower flows that follow.

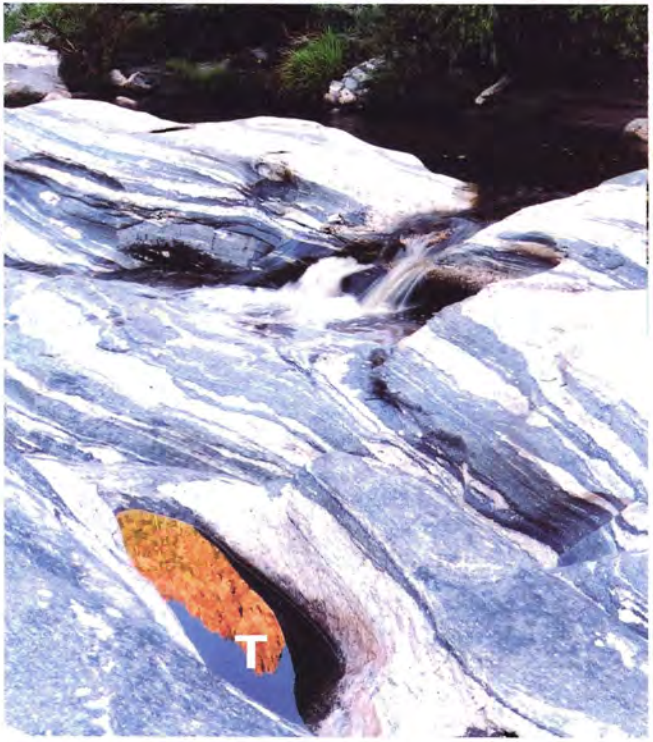


**Figure SC 10.2.** Early morning light on the canyon wall is reflected in water in a Tinaja (T).

Tinajas are critical sources of water for humans and wildlife that inhabit and travel through deserts. Some are more than 20 ft (6 m) deep and hold thousands of gallons (liters) of water months after the last rain. Please do not pollute or camp near these precious water resources.

# FEATURE SC 11 ▶ FAULT ZONE AND SLICKENSIDES

**Figure SC 11.1.** A fault (dashed line) in the fault zone between Shuttle Stops 8 and 9.

**Location:** Roadcuts along the Shuttle Route between Shuttle Stops 8 and 9.

This is the third place along the Shuttle Route where the Sabino Canyon fault is clearly exposed. Here the fault is actually a zone of closely spaced faults rather than a single fault. Several faults in the zone can be observed in the roadcuts (Figures SC 11.1 and 11.2). Rock in the entire interval has been fractured. The faults continue northward into the canyon wall just west of Shuttle Stop 9 (Figure SC 11.3).

Parallel scratches and polished surfaces called *slickensides* are common along a fault surface (Figures SC 11.4 and 11.5). These abraded and polished rock faces were produced by the grinding action that accompanied slippage along the fault. Slickensides indicate the direction of fault movement and help geologists map the path of faults along the landscape.

**Figure SC 11.2.** Another fault (dashed line) in the fault zone between Shuttle Stops 8 and 9.

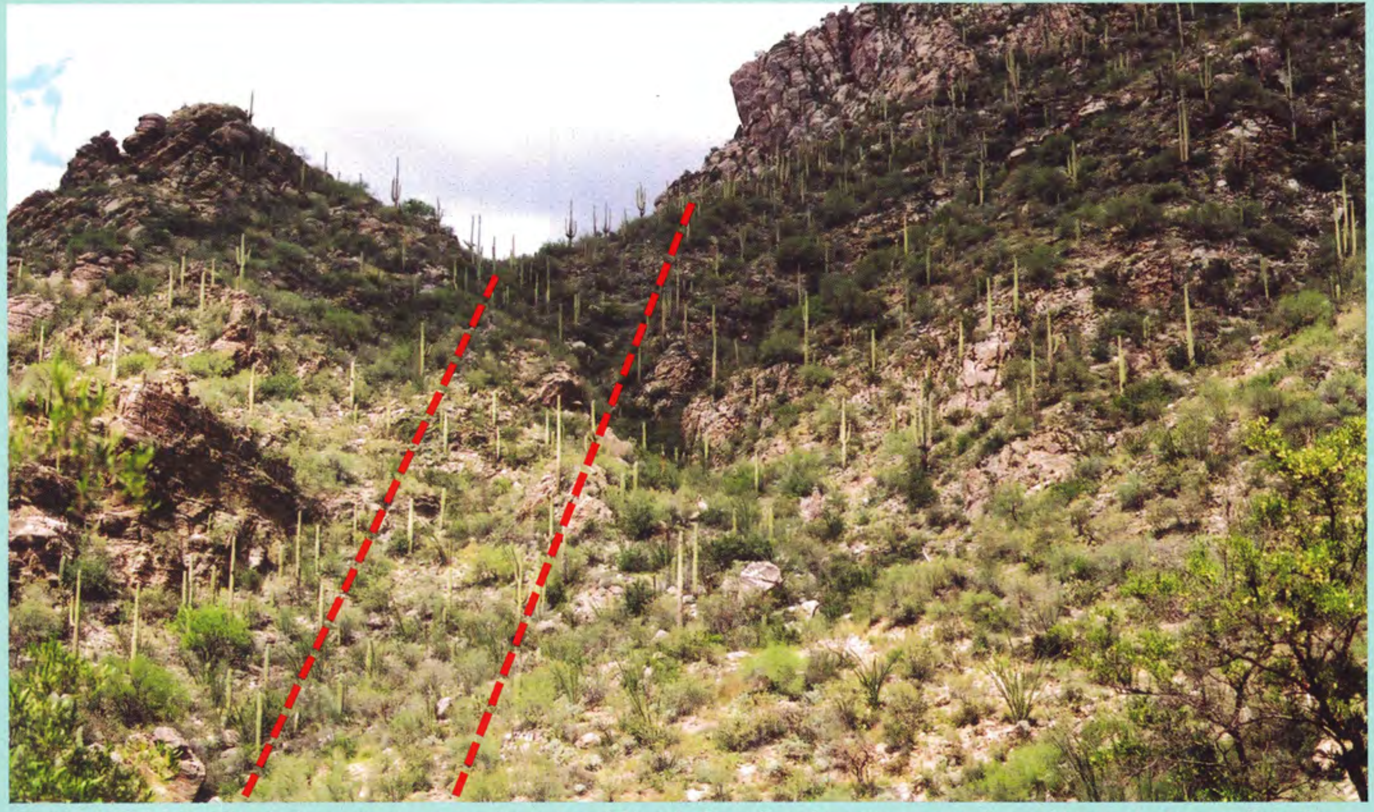


**Figure SC 11.3.** The fault zone passes to the west of Shuttle Stop 9 and continues northward beneath the notch in the ridge. The fault zone is the area between the dashed lines.

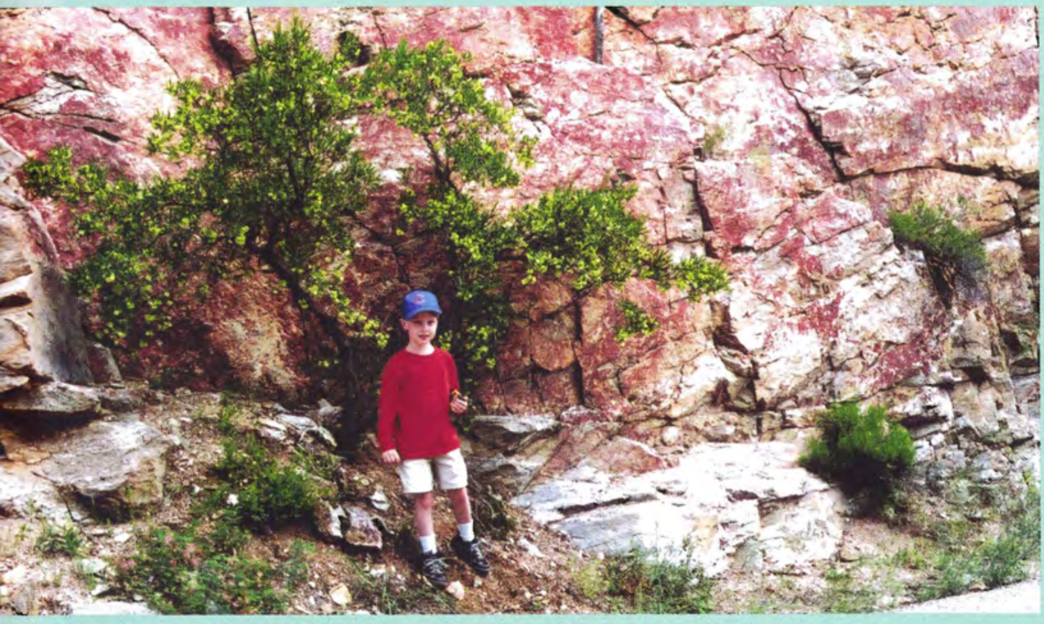


**Figure SC 11.4.** Fault surface, stained red by iron oxide, in a roadcut between Shuttle Stops 8 and 9.

**Figure SC 11.5.** Close-up view of slickensides on the fault surface in a roadcut between Shuttle Stops 8 and 9.

# GEOLOGIC FEATURES ALONG THE CATALINA HIGHWAY

**Location:** Mile 4.5, turnoff to Molino Canyon Vista scenic overlook.

The color-banded rock exposed along the highway all the way to this turnout and beyond is *gneiss* (Figures CH 1.1 and 1.2), the most common rock type in the southern Santa Catalina Mountains. The laminated texture of the gneiss, like that of innumerable, thin layers, gives the landscape an angular, ledgy nature.

Gneiss is a metamorphic rock. Intense heat and pressure caused minerals in the parent rock to recrystallize (metamorphose) to form the gneiss. This gneiss had two parent rocks: the Precambrian-age (1.4 billion years ago) Oracle granite and the Eocene-age (50 million years ago) Wilderness Suite granite. These granites formed from great molten masses of rock that cooled slowly miles below the Earth's surface.

The minerals feldspar, quartz, and mica crystallized as the granite slowly cooled. The Wilderness Suite granite is unusual in that it also contains crystals of red garnet.

Between 35 and 20 million years ago, when these granites were at a depth of 7 to 10 mi (10 to 15 km), the Earth's crust in this region was stretched and sheared in a southwest-northeast direction. The intense pressure and heat that accompanied this stretching deformed part of the deeply buried Oracle and Wilderness Suite granites into the gneiss that is exposed in the southern part, the forerange, of the Santa Catalina Mountains.

The southwest-northeast stretching is preserved as *lineation* in the gneiss. At temperatures of 600°F (350°C), the quartz crystals in the granites behaved like hot, soft plastic and smeared in long ribbons parallel to the direction of crustal stretching. The feldspar crystals, which are more brittle at this temperature, were rolled, crushed, and smeared—also in the direction of extension. These long, aligned streaks of deformed minerals give the gneiss its unique texture. The dark-colored bands are interpreted to be deformed Oracle granite; those of lighter colors once may have been Wilderness Suite granite.

Locally the gneiss is stained red and yellow by iron oxides. This is particularly common along fractures close to the Catalina fault, where hot fluids chemically altered the rock and deposited minute quantities of hematite and limonite.

**Figure CH 1.1.** Gneiss exposed in roadcuts near the Molino Canyon Vista turnoff.

**Figure CH 1.2.** Close-up view of gneiss showing contortion that occurred when the rock was in a plastic state.

# FEATURE CH 2 ▶ TINAJA

**Figure CH 2.** Tinajas (T) in Molino Creek at Molino Canyon Vista.

**Location:** Mile 4.5, Molino Canyon Vista scenic overlook. Walk the trail for about 120 yd (about 110 m) to the stream bed to see this feature.

The rock basins that hold water in Figure CH 2 are *tinajas* (pronounced tee-na'-has), the Spanish word for a large earthen water jar fired so that water will seep to the vessel's surface and keep its contents cool by evaporation. Tinajas or rock tanks, as they are called in English, are best formed in the bedrock channels of steep canyons cut into desert mountain ranges.

Boulders, cobbles, and pebbles tumbled along by swiftly flowing water during flash floods act as cutting tools that gouge out weak zones in the underlying bedrock. The upstream sides of these enlarging depressions, which bear the full impact of the moving rock debris, are consequently deeper than the downstream sides, which are breached by outlet channels. Because of this asymmetrical shape, tinajas are flushed clear of organic and rock debris by flash floods and filled with water by the slower flows that follow.

Tinajas are critical sources of water for humans and wildlife that inhabit and travel through deserts. Some are more than 20 ft (6 m) deep and hold thousands of gallons (liters) of water months after the last rain. Please do not pollute or camp near these precious water resources.

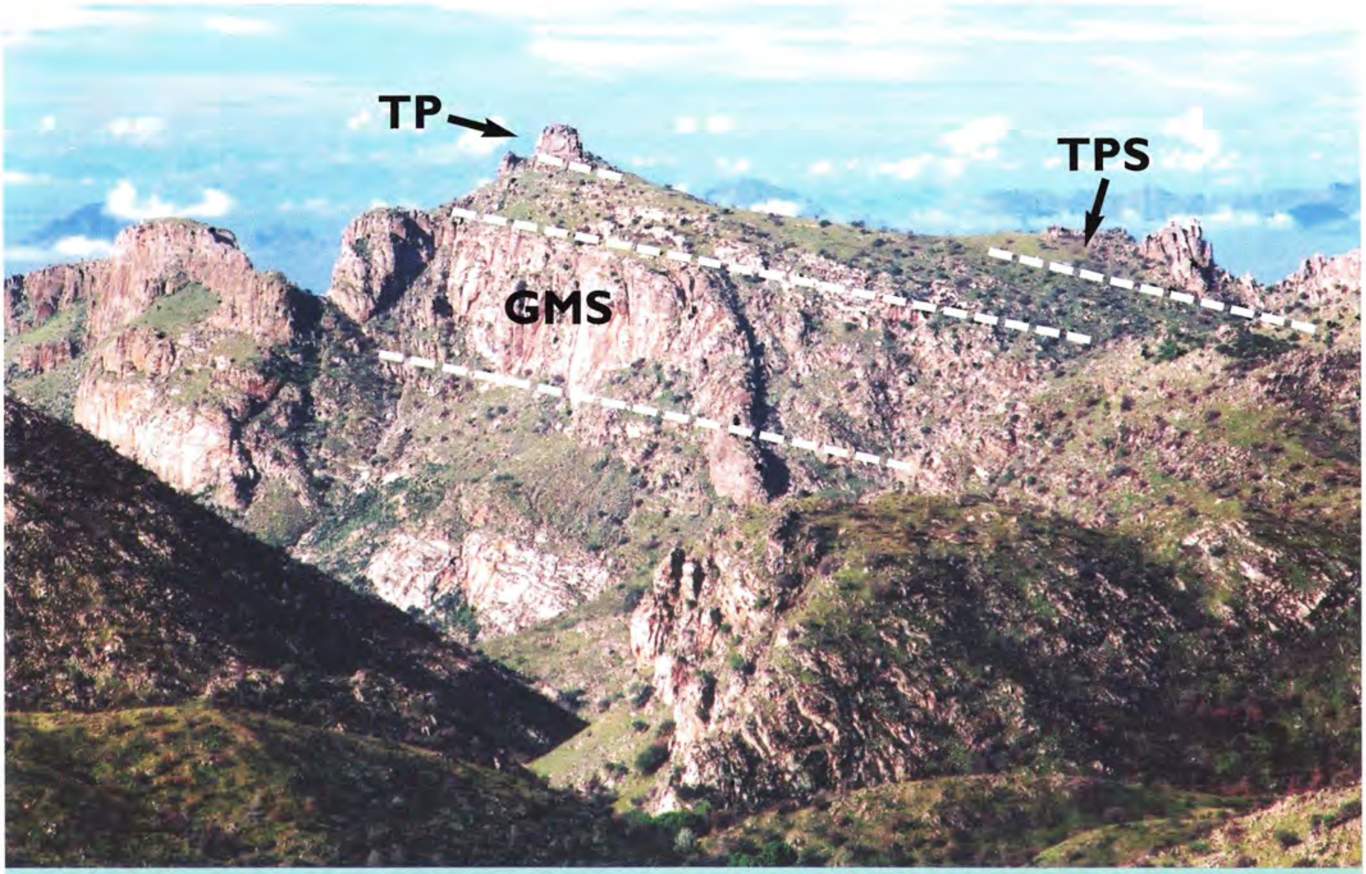


**Figure CH 3.** Thimble Peak (TP), the Thimble Peak sill (TPS), and the Gibbon Mountain sill (GMS) are marked by dashed lines.

**Location:** Mile 8.4, Thimble Peak Vista scenic overlook.

Thimble Peak (Figure CH 3) is an erosional remnant of a thick, layer-shaped intrusion of granite called a *sill*. About 50 million years ago (Eocene time), when this granite was hot and molten, it was injected into the 1.4-billion-year-old Oracle granite—a gigantic mass of once-molten rock that underlies much of this part of Arizona. The sill cooled at great depth, was uplifted near Earth's surface, and has been exposed by erosion.

Sills are tabular injections of molten rock (magma) that wedge open and penetrate layers and other planes of weakness in the host rock. They range in thickness from a fraction of an inch to thousands of feet and can be miles in length. This sill, called the Thimble Peak sill, reaches a thickness of 2,600 ft (800 m). The Thimble Peak and other sills make up much of the rock in this part of the southern Santa Catalina Mountains.

Sills are of considerable geologic importance. Multiple injections of sills can greatly thicken the local crustal rocks, as they do in the Santa Catalina Mountains. In addition, sills that are harder than the surrounding host rock commonly erode to form high cliffs (GMS), such as those below Thimble Peak. In some areas, the interaction of the sill magma with the adjacent host rock produces precious and industrial mineral deposits.

# FEATURE CH 4 ▶ PINNACLES

**Location:** Mile 14.1, Windy Point scenic overlook. Park and walk to the observation area on the left (west) side of the highway. The pinnacles are well developed on the slopes below.

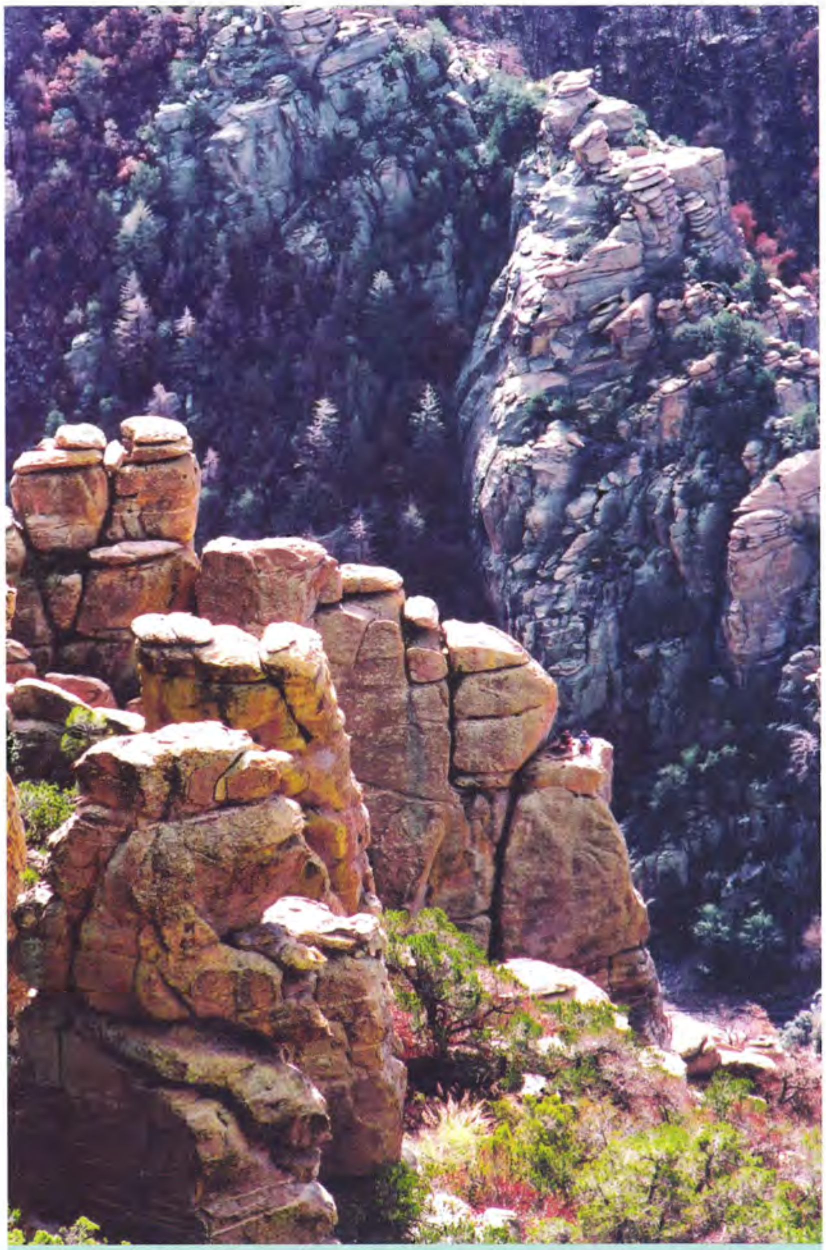


**Figure CH 4.** Pinnacles at Windy Point. Rock climbers for scale.

The dramatic pinnacles in Figure CH 4 are developed in the Wilderness Suite granite cliffs. These slender spires are the products of surface weathering and erosion by running water guided by deep joints (cracks) in the granite.

Joints serve as avenues along which water and tree roots can penetrate the granite. Rock fracturing, caused by expansion that occurs when water freezes, and wedging by plant roots, enlarges the joints. Along the joints chemical decomposition from slightly acidic rain and snowmelt causes the mineral biotite to weather to clay. This greatly weakens the interlocking mineral grains in the granite, causing it to breakdown into its major component minerals – quartz and feldspar.

Running water then flushes the weathered products from the joints, cutting them deeper and wider. The rock between the joints is left standing as pinnacles. The pinnacles appear to be leaning toward the cliff because the joints in the bedrock are at an angle from the vertical.

The pinnacles at Windy Point are impressive testimony to the important role that rock structure – in this case joints – plays in the development of the landscape.

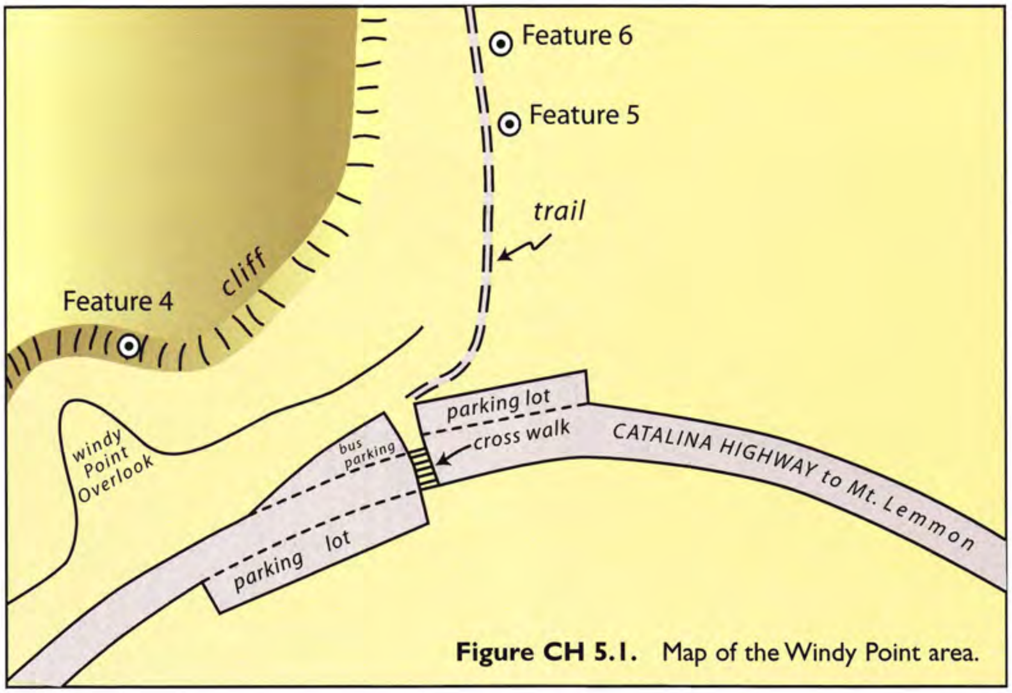


**Figure CH 5.1.** Map of the Windy Point area.

**Location:** Mile 14.1, Windy Point Vista scenic overlook. Cross the Catalina Highway via the crosswalk. At the far end of the stone retaining wall is a narrow trail. Walk this trail for about 300 yd (275 m) to view this feature (Figure CH 5.1)

Many relatively level granite surfaces in this area contain flat-bottomed, circular to irregularly shaped depressions that commonly have overhanging sidewalls (Figure CH 5.2). These *solution pans* or *gnammas*, which are up to 3 ft (1 m) across and 4 to 6 in (10 to 14 cm) deep, can hold rain and snowmelt for days.

Solution pans form at points of rock weakness (joints, areas of lichen disintegration, or flaked surfaces) and expand by chemical and lichen-induced weathering. Periodic pooling of water results in the chemical alteration of the minerals in the nearby rock. Some minerals dissolve, some oxidize, and others are changed to clay minerals. Lichens and algae flourish in the more humid environments of the pans and decompose the granite grain by grain. The rock disintegrates slowly and the resulting debris is swept and flushed from the enlarging solution pans by wind and heavy rains.

**Figure CH 5.2.** Solution pans full of water after a recent rain.

# FEATURE CH 6 ▶ TAFONI AND CASE HARDENING

**Location: Mile 14.1,** Windy Point Vista scenic overlook. Cross the Catalina Highway via the crosswalk. At the far end of the stone retaining wall is a narrow trail. Walk along this trail for about 350 yd (about 320 m) to view these features. Please refer to the map (Figure Ch 5.1).

**Figure CH 6.1.** Tafoni developed in granite.

**Figure CH 6.2.** Case-hardened rock surface.

The cavities weathered in the granite in Figure CH 6.1 are called *tafoni* (pronounced ta-fo'-nee). They occur in many different types of rock and in a great variety of climates, but are particularly visible in arid and semi-arid climates where their shapes are not obscured by soil and vegetation.

These cavernous openings, which can measure several yards (m) in diameter, are commonly aligned along joints, bedding planes, or other zones of weakness in bedrock. Tafoni, the products of several processes acting in concert, are particularly common where rock faces have developed a hardened crust of mineral salts that were drawn from the interior of the rock. This "case-hardened" outer surface (Figure CH 6.2.A) is resistant to weathering and erosion. Small breaks in this resistant surface, however, enlarge relatively rapidly and, in time, penetrate the softer interior of the rock. Within these shaded cavities, higher humidity and lower temperatures cause rock to disintegrate more rapidly than outside surfaces. Cavity walls are usually crumbling and flaking due to the expansion of clay minerals that swell when wet, the growth of ice crystals, and the dissolving of mineral cement that binds rock grains together.

Some cliffs contain fossil tafoni. Interiors of fossil tafoni are either case-hardened or covered with lichens or rock varnish – a clayey, iron-manganese rind. See Feature SC 4 in the Sabino Canyon section. Shaped by processes that have slowed or ceased, these openings are relics from an earlier period when the climate was more humid. Tafoni weathering, common throughout the Southwest, is but one of the numerous processes that reduce solid rock to fragments that are then swept away by erosion.

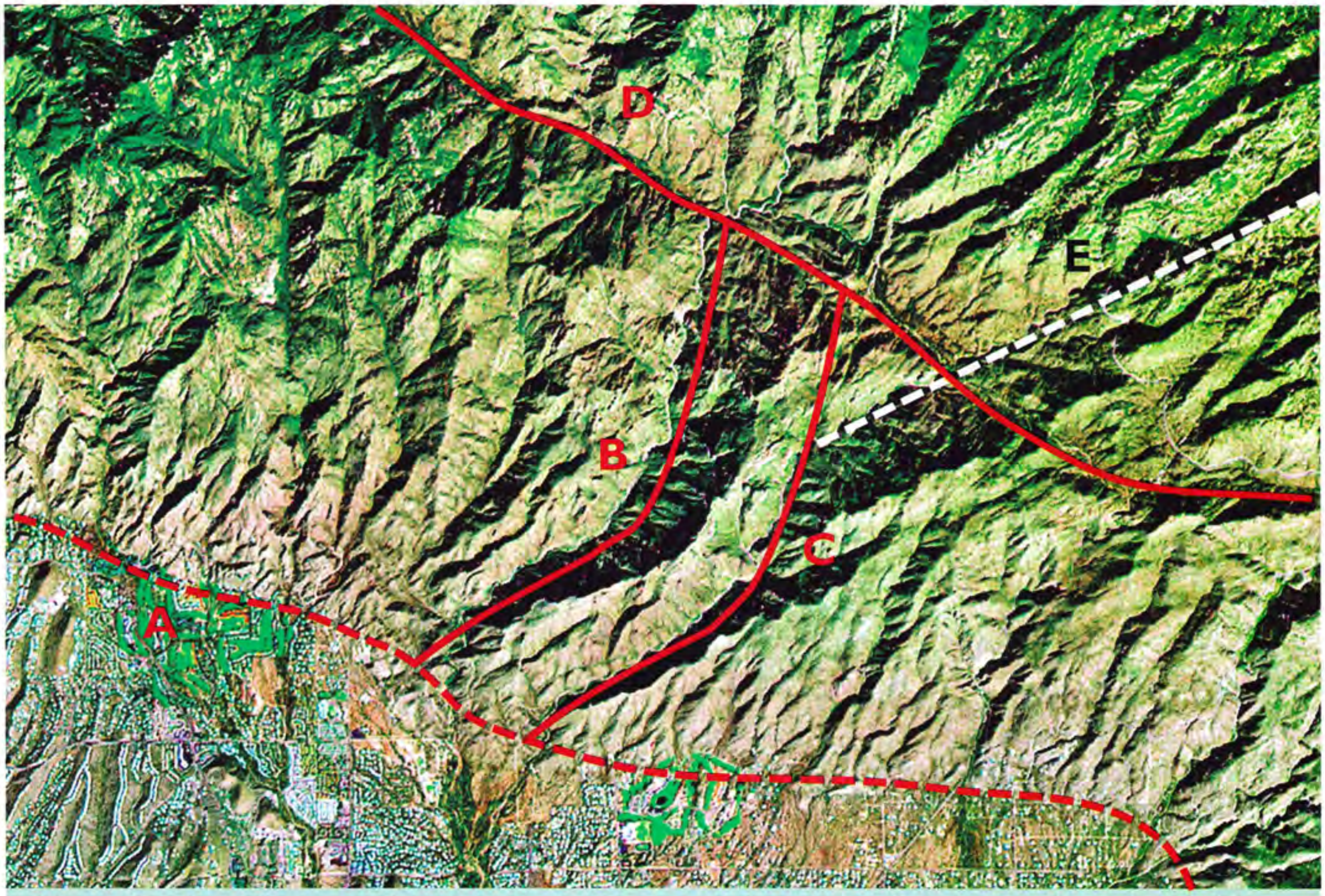


**Figure CH 7.** Satellite image of the Santa Catalina forerange. A=Buried trace of Catalina detachment fault, B=Sabino Canyon fault, C=Bear Canyon fault, D=Romero Pass fault zone, and E=Upper Bear Canyon.

**Location:** Mile 14.5, Geology Vista scenic overlook.

Sabino, Bear, Molino and many other canyons in this part of the Santa Catalina Mountains have unusually straight courses. Tributary canyons also tend to join these major canyons at high angles (Figure CH 7). A major reason for this relationship is that these canyons have developed along *joints* and *faults*.

Joints are the sets of natural cracks found throughout almost all bedrock. Some of the joint sets formed during the cooling and contraction of the once-molten granite that makes up much of the range. Other joint sets are the result of stress associated with faulting, arching and other movements in the Earth's crust that occurred long after the emplacement of the granite or the conversion of the granite to gneiss. Some of these cracks are major features that can be traced for miles across the mountain range.

Faults are fractures in the bedrock along which movement has taken place. The tremendous friction and grinding action generated as fault surfaces slide past each other shatters and pulverizes the local bedrock.

Joints and fault zones are deepened and widened by chemical and physical weathering and erosion. Water seeps into these cracks, freezes and expands, and shatters the adjacent rock. Plant roots also wedge open joints and fault-fractured rock. Slightly acidic groundwater converts some minerals to clay, causing the granite and gneiss to disintegrate. Running water from rain and snowmelt seeks out these weathered zones along joints and faults, eroding them into the deep, rectangular system of canyons that is cut into the front range of the Santa Catalina Mountains.

# FEATURE CH 8 ▶ HALF GRABEN: SAN PEDRO RIVER VALLEY

**Figure CH 8.1.** Photo of the San Pedro River Valley and the Galiuro Mountains.

**Location:** Mile 17.6, San Pedro Vista scenic overlook.

The San Pedro River Valley between the Santa Catalina and the Galiuro Mountains (Figure CH 8.1) is a *half graben*. The half graben formed long before the San Pedro River developed. The valley is a block of bedrock (Figure CH 8.2) that was dropped down between two breaks in the Earth's crust, called faults, along which movement occurred.

These faults, and many others in the area, moved when the Earth's crust in this part of North America was stretched and pulled apart in a northeast-southwest direction beginning about 25 million years ago. As stretching continued some of the fault-bounded blocks of rock subsided as much as 1.2 mi (2 km) due to gravity, forming long, trench-like basins such as the San Pedro and Tucson basins. Crustal blocks that did not subside stand as mountains such as the Galiuros on the east side of the San Pedro River. Sediment eroded from the adjacent ranges once filled the basins, and is now being removed by river systems such as the San Pedro that developed within the last million years.

This topography of alternating basins and mountains extends from central Mexico to Oregon and is refered to as the Basin and Range geologic province (Figure D). Grabens (Figure CH 8.3) are similar basin structures in which the crustal rock between two faults subsided without being tilted. The Rift Valleys of East Africa, Death Valley, and the Rhine Graben are well known grabens. Mid-oceanic rift valleys are graben and half graben structures that extend like a seam around the Earth for thousands of miles and are the birthplace of new igneous rock that floors the ocean basins.

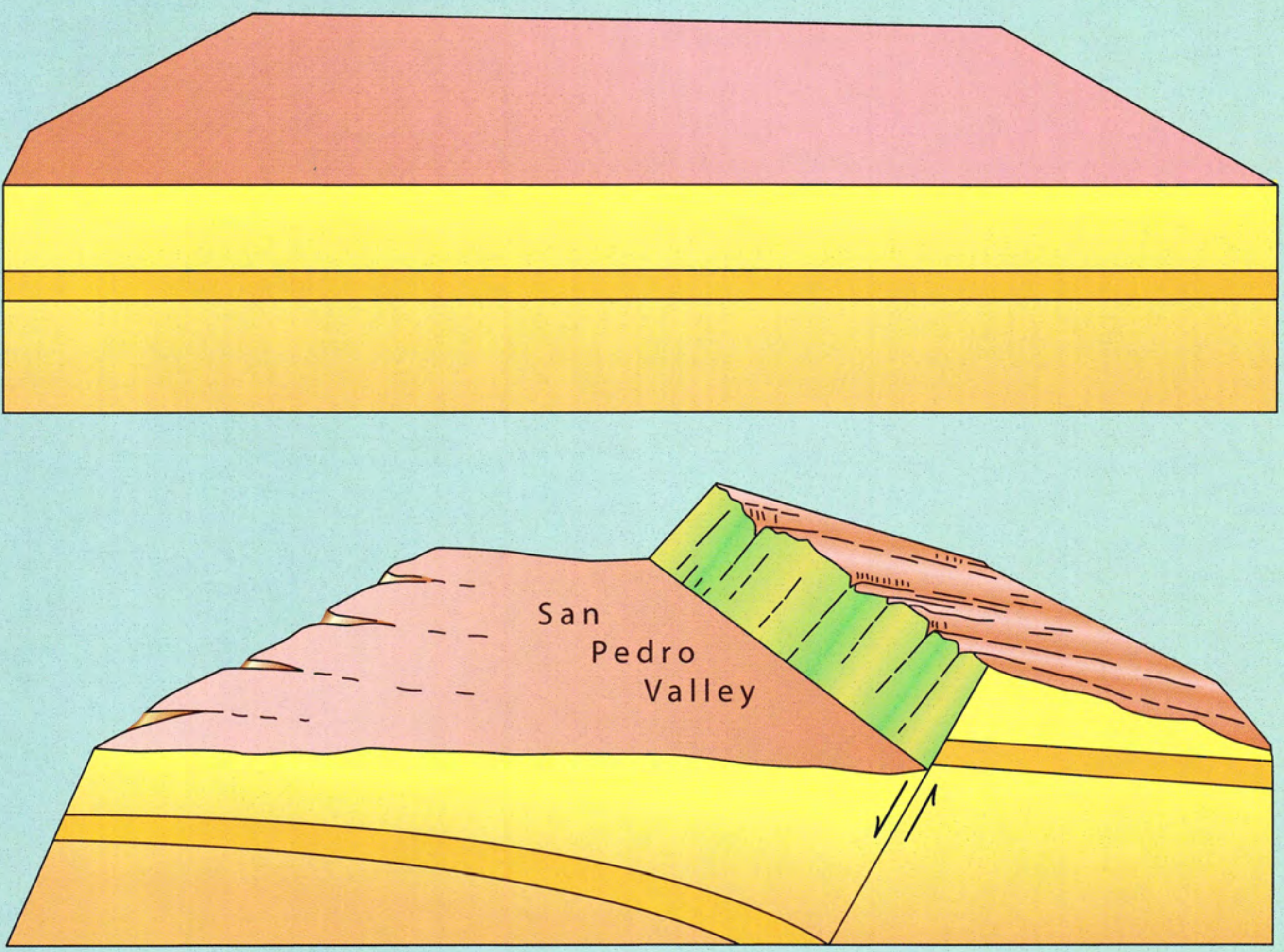


**Figure CH 8.2.** Block diagram illustrating the formation of the San Pedro half graben.

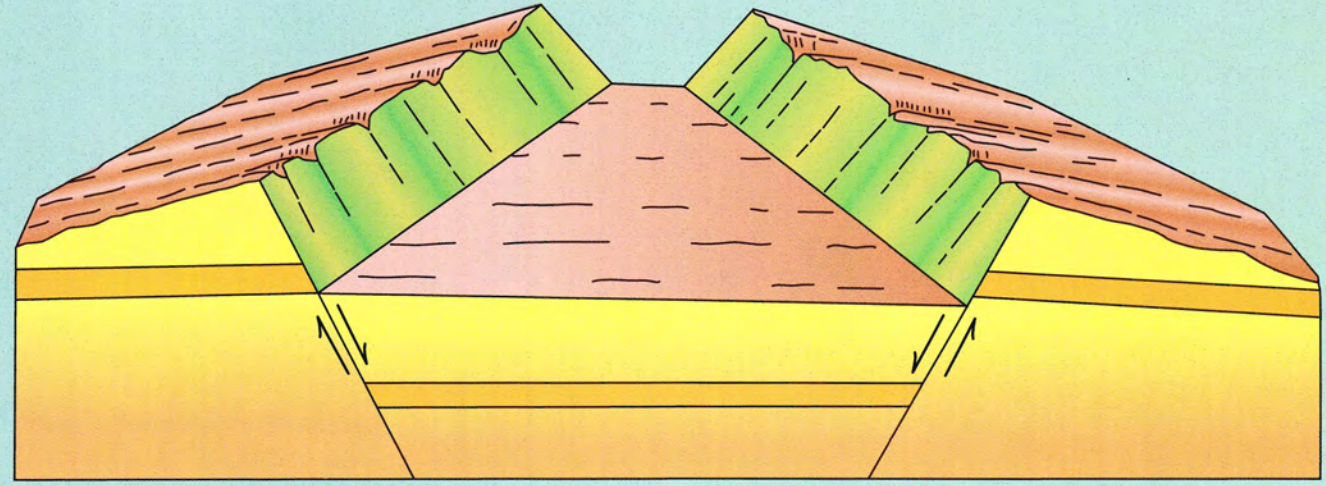


**Figure CH 8. 3.** Block diagram illustrating the formation of a graben.

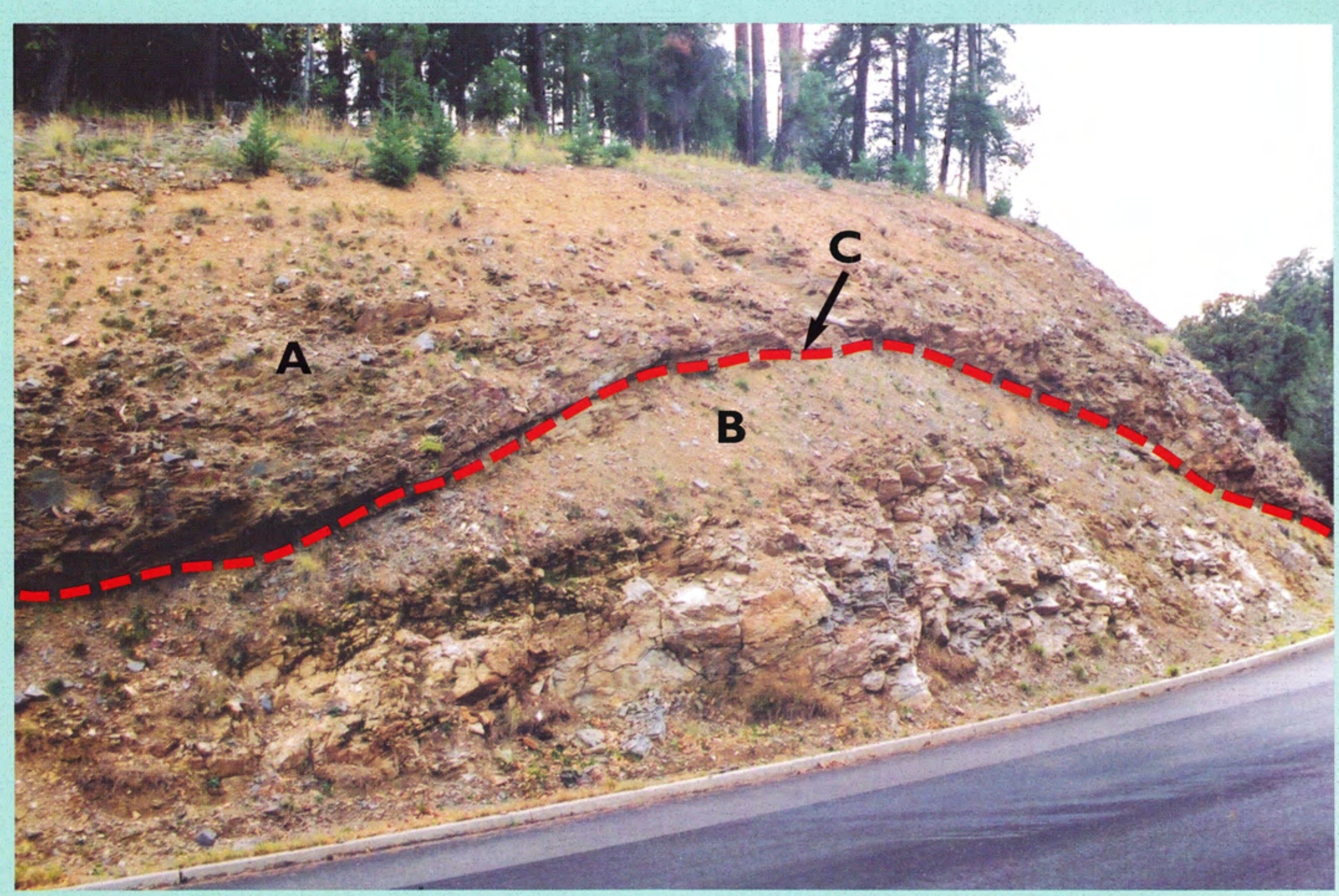


**Figure CH 9.1.** Dripping Springs Quartzite (A) and Mescal Limestone (B) separated by the Bear Wallow thrust fault (C).

**Location:** Mile 21.9, road cut on the east (right) side of the highway, about 0.25 mi (about 400 m) past the Box Canyon turnoff.

The principle of *superposition*—that younger rocks are found above older ones in vertical sequence—is basic to geologic thought. Yet here, in this part of the Santa Catalina Mountains, the rocks are not always in the order that they were deposited. For example, the older Dripping Spring quartzite (Figure CH 9.1, A) rests on the younger Mescal limestone (B). The order has been reversed by movement along the thrust fault (C) that separates these two rock layers.

Thrust faults are produced by compression of the rocks near the Earth's surface. Under such pressure the rocks break and slide along a low-angle fracture (fault), causing slices of older rock (Figure CH 9.2, A) to override younger rock (B) nearer the surface. In this case, the Dripping Spring quartzite was thrust up and over the Mescal limestone.

Tremendous stress in the Earth's crust causes fault surfaces to slide together. This grinding and frictional sliding produced a zone of powdered rock, called *gouge,* along this fault. Gouge is of geologic importance because it commonly forms a permeable zone that allows groundwater to rise to the surface as springs.

Aside from creating geologic puzzles such as inverted strata, thrust faulting is a significant mountain-building process. Ancient and modern global, larger-scale horizontal displacements of miles of bedrock along thrust faults have built majestic ranges such as the Alps and Himalayas.

The origin of the Dripping Spring quartzite and the Mescal limestone and their location near the summit of the Santa Catalina Mountains is of great interest. Both of these Precambrian (1.2 billion years ago) rock units are exposed over large areas of southern Arizona. These rock units were named for the Dripping Spring Mountains and Mescal Mountains near Globe, Arizona, where they were first described and named by geologists. The quartzite was deposited as river or beach sands, which became cemented into sandstone. Later, the sandstone was converted to erosion-resistant quartzite by more intense cementation by minerals from groundwater. The limestone originated as fine calcium carbonate sediment that was deposited on a continental shelf beneath shallow seas. Heat and pressure then changed the limestone to marble. The formation of the metamorphic core complex dome (see the General Geology section) that led to the formation of the Santa Catalina Mountains uplifted the quartzite and limestone (marble) to their location on the roof of the range.

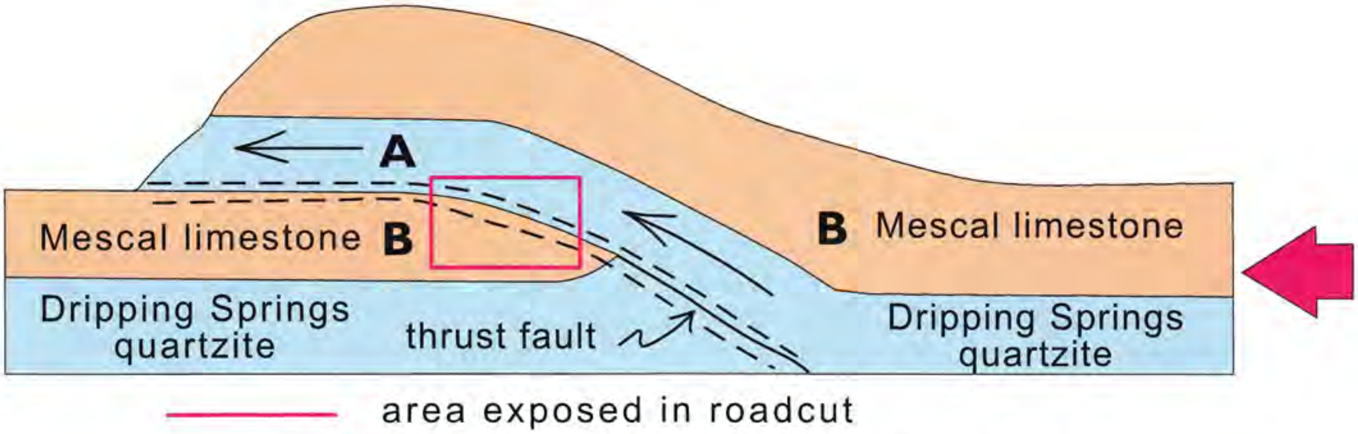


**Figure CH 9.2.** Diagram illustrating the formation of a thrust fault.

# FEATURE CH 10 ▶ PINAL SCHIST

**Figure CH 10.** Pinal Schist.

**Location:** Mile 22.4, just north of the intersection of Soldier Camp Road.

The dark gray rock exposed in this road cut is the *Pinal Schist* (Figure CH 10). At about 1.65 billion years old, it is the most ancient rock in southern Arizona. The Pinal Schist was originally deposited as thick layers of sandstone, siltstone, and shale. These rocks probably represent a deep-sea environment that received much sand, silt and clay from a nearby continent.

Over time these sedimentary layers were buried at depth and subjected to intense heat and pressure, transforming them into new rocks—called schists and phyllites. These highly altered rocks bear little resemblance to the original sedimentary layers. The schists are silver-gray in color and are thinly bedded layers of quartz and mica; the phyllites have a satiny appearance with fine, wavy planes of aligned minerals such as mica. The schists and phyllites are highly fractured by faulting and were elevated to this high elevation by the uplift of the Santa Catalina Mountains.

All rocks are divided into three categories. Sedimentary rocks are composed of rock fragments or precipitated material that was deposited by standing or running water, ice, or wind. Igneous rocks were once so hot they were molten. The Pinal Schist is an example of the third category—metamorphic rocks. These were once sedimentary, igneous, or metamorphic rocks that have been chemically and structurally transformed into new material by intense heat and pressure. Sometimes the change is so great that it is not possible to identify the parent rock.

**Figure CH 11.** View of the San Manuel area (arrow) from Aspen Vista.

**Location:** Mile 23.1, Aspen Vista scenic overlook.

The tailings dam and smelter smoke stacks of the San Manuel copper mining and smelting community in the San Pedro Valley can be viewed from this overlook (Figure CH 11). The copper mineralization of the bedrock in the San Manuel area is the result of an intrusion of a thick, tabular mass of molten rock that occurred about 65 to 69 million years ago. The intrusion penetrated and chemically altered the surrounding 1.4-billion-year-old Oracle granite at a depth of approximately 1 mi (1.6 km).

Intrusions of this type are surrounded by a zone of rock, called an *aureole*, which has been chemically changed by heat, pressure, and the release of hot mineral-laden solutions. Within the aureole are concentric bands of minerals that reflect changing temperature, pressure, and chemical conditions with increasing distance from the intrusion. Copper and other metals, once dissolved in the hot fluids, crystallized and filled minute openings and veins in the surrounding rock. Copper is the most abundant metal in the San Manuel area and is disseminated in the mineralized rock, the *ore*. Ore in the San Manuel mining district contains only about 0.80 percent copper, which is relatively low grade in comparison with ores from Zambia, Chile, and New Guinea.

Mining operations began at San Manuel in 1955. The mine closed in 1999 due to competition from richer mines in other parts of the world with lower labor costs – a fate shared by a number of other southern Arizona copper mines.

Copper has many important uses, including in electrical equipment, plumbing, paint, and wiring. It is alloyed with tin to make bronze and with zinc to make brass.

# FEATURE CH 12 ▶ LEATHERWOOD GRANODIORITE

**Location:** Mile 24.7, intersection of the Catalina Highway with the Control Road; road cut on the northeast corner of the intersection.

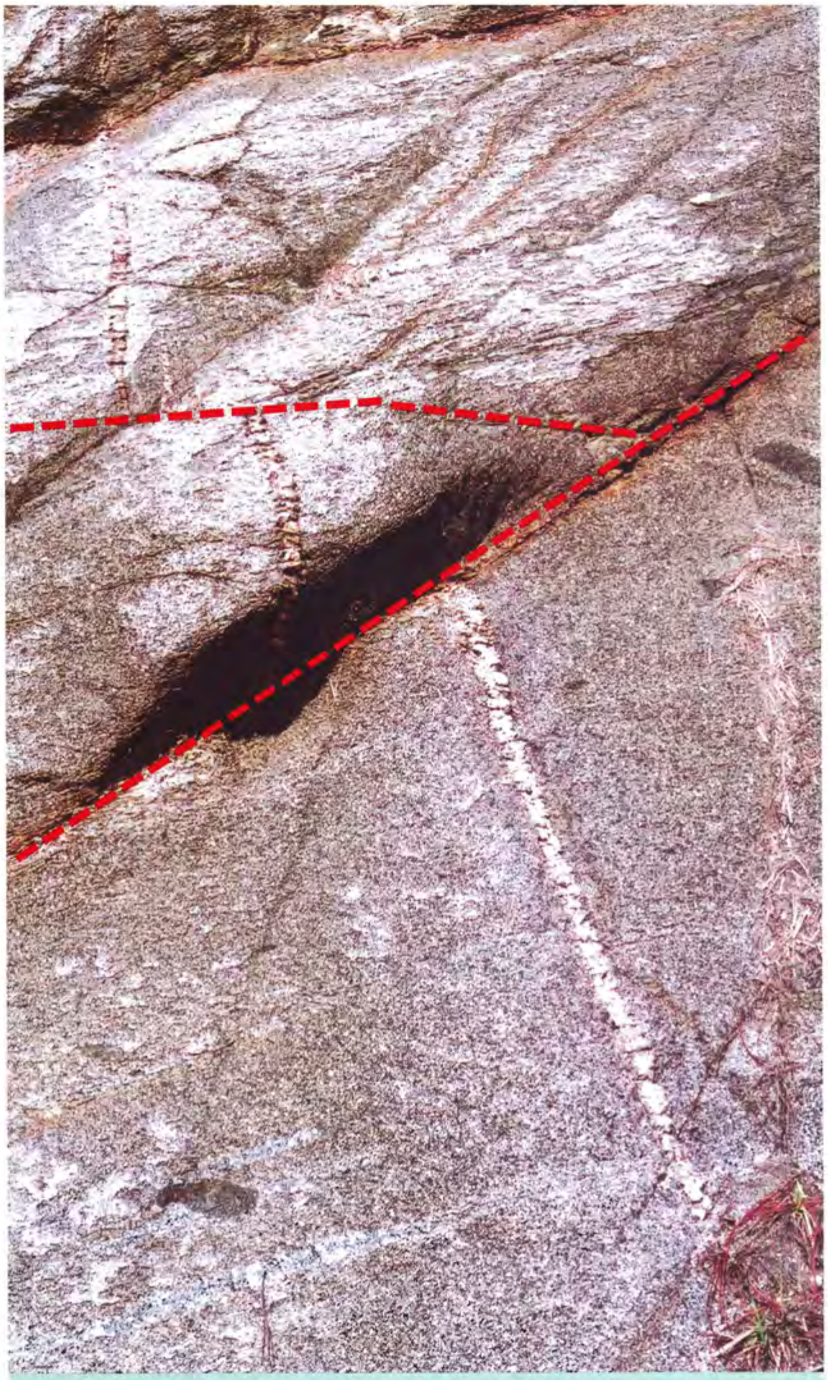


**Figure CH 12.** Leatherwood granodiorite. The thin granite dike (pink) has been offset by two faults (dashed).

The crumbly, light and dark speckled rock (Figure CH 12) exposed in cuts along this road is the 70-million-year–old *Leatherwood Granodiorite.* Granodiorite, like other granitic type rocks, originated as a mass of molten rock that cooled miles below the Earth's surface. It is distinguished from other granitic rocks by its high magnesium, iron and calcium content.

Named for the Leatherwood mines near Marble Peak, where it was first described in the geologic literature, this granodiorite is one of several great masses of once-molten rock that make up much of the Santa Catalina Mountains. The Leatherwood granodiorite intruded the older Oracle granite and rocks of the Apache Group at a depth of perhaps several miles. Uplift, faulting and erosion have exposed the granodiorite near the summit of the range. The main intrusion was sheet-shaped and had a thickness of about 1,000 ft (300 m). Smaller bodies of magma, offshoots from the main intrusion, occur in Molino Canyon and other parts of the Santa Catalina Mountains.

The Leatherwood granodiorite is of economic interest because mineral ores formed where the magma intruded and altered marble and other limey rocks. Other mineral deposits occur where hot solutions flowed through fault shatter zones in the granodiorite.

The white veins of rock in the granodiorite are dikes (see Feature CH 14).

**Figure CH 13.** Xenolith (arrow) in the Leatherwood granodiorite.

**Location:** Mile 24.7, northeast corner of the intersection of Catalina Highway and the Control Road (same location as Feature CH 12).

The dark-colored inclusions in the lighter-colored Leatherwood granodiorite in Figure CH 13 are *xenoliths* (pronounced zeno-liths)(Greek for "foreign stone"). Xenoliths are fragments of older rock that became incorporated into the younger hot, viscous magma before it cooled to form the granodiorite. The temperature of the magma was not high enough to melt the trapped xenoliths.

Xenoliths, common features in igneous (once-molten) rocks, range in size from a fraction of an in (cm) to many yd (m). The fact that they are unmelted provides an indication of the temperature of the host magma at the time of implacement.

# FEATURE CH 14 ▶ DIKES

**Figure CH 14.** Pegmatite dikes intruded into the Leatherwood granodiorite.

**Location:** Mile 24, turn right on the Mt. Lemmon Ski Valley Road. Dikes are exposed in roadcuts on the right side of the Ski Valley Road, 40 yd (about 37 m) past the intersection.

The veins of light-colored rock in this rock face are *pegmatite dikes* (Figure CH 14). A dike is an intrusion of molten rock that cuts across the layers or fabric of the rock that is invaded. The molten rock, called *magma*, originated miles below the Earth's surface. The magma migrated under great pressure and wedged open and filled cracks in the older, darker-colored Leatherwood granodiorite (Feature CH 13). Over time the magma cooled to form pegmatite, a type of granite composed of relatively large mineral crystals.

Dikes are of economic interest because precious and industrial metals have been found in the recrystallized zones that commonly occur along their margins.

# SUGGESTED READINGS

Bykerk-Kauffman, Ann, 1990, Structural evolution of the northeastern Santa Catalina Mountains, Arizona: A glimpse of the pre-extensional history of the Catalina complex (Ph.D. thesis): Tucson, University of Arizona, 195 p.

Crittenden Jr., M.D., Coney, P.J., and Davis, G.H., 1983, Cordilleran metamorphic core complexes: Geological Society of America Memoir 153, 490 p.

Davis, G.H. and Coney, P.J., 1979, Geologic development of Cordilleran metamorphic core complexes: Geology, v. 7, pp.120-124.

Dickinson, W.R., 1992, Geologic map of Catalina core complex and San Pedro trough, Pima, Pinal, Graham and Cochise Counties, Arizona: Arizona Geological Survey Contributed Map 92-C, scale 1:125,000.

Force, E. R., 1997, Geology and mineral resources of the Santa Catalina Mountains, southeastern Arizona: A cross-sectional approach: Tucson, University of Arizona, Center for Mineral Resources, Monographs in Mineral Resource Science No. 1, 135 p.

_____ 2001, Field trip guide to Sabino Canyon and the Mount Lemmon Highway, Pima County, Arizona: Arizona Geological Survey Contributed Report 01-A, 35 p.

Granger, H.C., and Raup, R.B., 1964, Stratigraphy of the Dripping Spring Quartzite, southeastern Arizona: U.S. Geological Survey Bulletin 1168, 119 p.

Hanson, J.B., 1966, Petrography and structure of the Leatherwood Quartz Diorite, Santa Catalina Mountains, Pima County, Arizona (Ph.D. thesis): Tucson, University of Arizona, 104 p.

Naruk, S.J., and Bykerk-Kauffman, Ann, 1990, Late Cretaceous and Tertiary deformation of the Santa Catalina metamorphic core complex, Arizona: Arizona Geological Survey Special Paper 7, pp. 41-50.

Pelletier, J.D., 1957, Geology of the San Manuel mine: Mining Engineering, v. 7, 760 p.

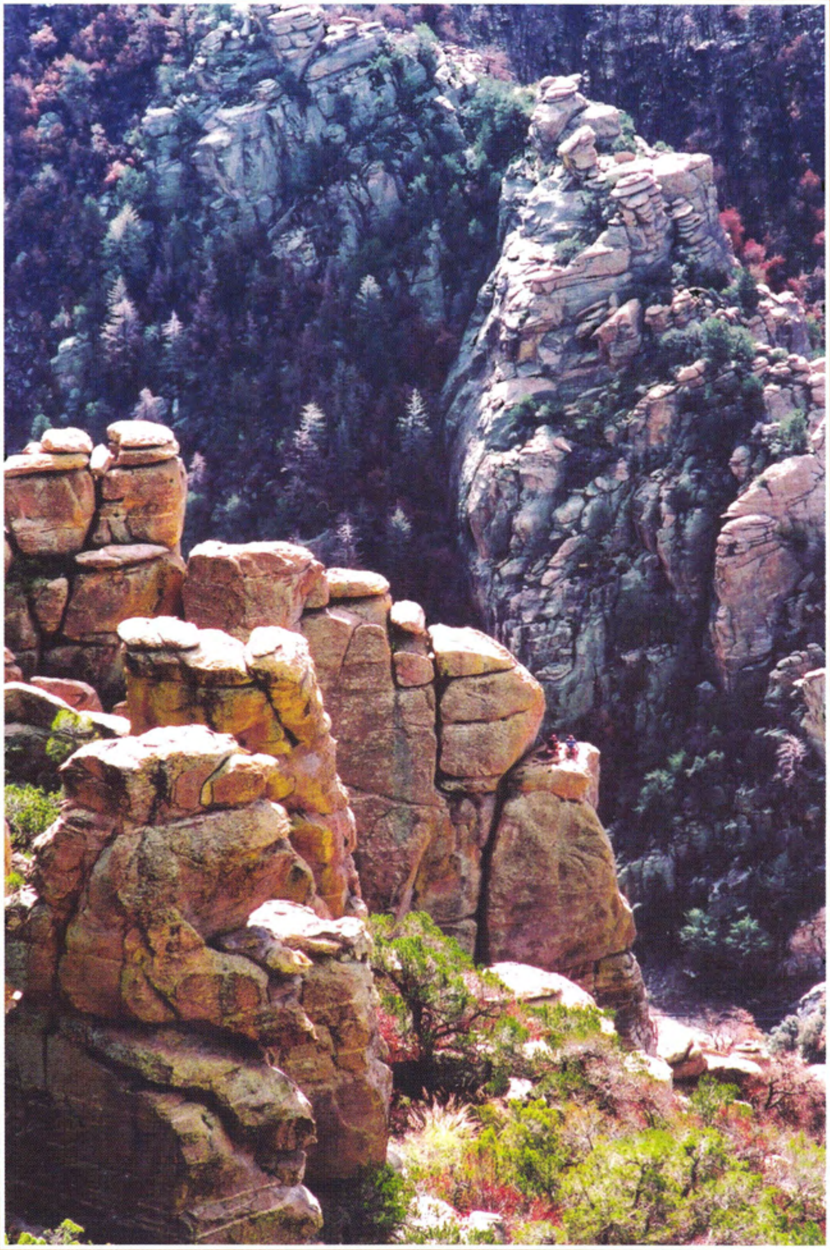
Pelletier, J.D., and Creasey, S.C., 1965, Ore deposits, *in* Creasey, S.C., Geology of the San Manuel area, Pinal County, Arizona: U.S. Geological Survey Professional Paper 471, pp. 29-60.

Shakel, D.W., 1974, The geology of layered gneisses in part of the Santa Catalina forerange, Pima County, Arizona (M.S. thesis): Tucson, University of Arizona, 233 p.

Spencer, J.E., 2000, Possible origin and significance of extension-parallel drainages in Arizona's metamorphic core complexes: Geological Society of America Bulletin, v. 112, no. 5, pp. 727-735.

Spencer, J.E., and Reynolds, S.J., 1989, Middle Tertiary tectonics of Arizona and adjacent areas, *in* Jenney, J.P., and Reynolds, S.J., eds., Geologic evolution of Arizona: Arizona Geological Society Digest 17, pp. 539-574.

Young, D. P., 1988, The history of deformation and fluid phenomena in the top of the Wilderness Suite, Santa Catalina Mountains, Pima County, Arizona (M.S. thesis): Tucson, University of Arizona, 144 p.



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# INTRODUCTION

Upper Sabino Canyon Road, also known as the Sabino Canyon Shuttle Route, and the Catalina Highway to Mount Lemmon offer a variety of spectacular geologic features. Because of the relatively sparse vegetation in the lower part of the range, most of these features are easy to recognize and photograph.

Some of these features are common throughout this southern part of the Santa Catalina Mountains. Others occur in many other parts of the American Southwest.

This booklet is your field guide to the geology of this spectacular mountain landscape. All of the geologic features described in the text can be reached by short walks from the Sabino Canyon Shuttle Route or the Catalina Highway. This book is written for the visitor who has an interest in geology, but who may not have had formal training in the subject. It may also help assure that the visiting geologist does not overlook some of the features described.

To set the stage, I have briefly described the area's geologic setting and history. In the following pages, emphasis is given to description of geologic features that are common in this landscape. Precise directions to each feature are provided in the text. Three features – gneiss, sill, and tinajas – are discussed in both the Sabino Canyon and the Catalina Highway parts of the guidebook.

Locations of the geologic features and access roads and trails are shown on Figures A and B. The Sabino Canyon Shuttle Route is not open to private vehicles; transportation is available by shuttle bus should you not have the time to hike the entire road. The Catalina Highway, a paved mountain road with curves and steep grades, should be driven with care. Numerous turnouts make it easy for one to enjoy the drive at a leisurely pace.

Another purpose of the field guide is to provide the reader with an understanding of the dynamic processes that have shaped this exceptional landscape. You will encounter many of the features discussed in the text again and again as you continue to explore the Southwest. I hope that your experience in Sabino Canyon and along the Catalina Highway will enhance the pleasure of those explorations.