Field Trip Guide to Sabino Canyon and the Mount Lemmon Highway, Pima County, Arizona

by

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U.S. Geological Survey

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Figure 1. Map showing location of all field stops.

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PART A: SABINO CANYON

INTRODUCTION

The banded crystalline rocks of Sabino Canyon are a strong aesthetic component of the canyon's dramatic views. Certainly these rocks have attracted much attention from geologists. Until recently they were much-debated but poorly understood. When finally decoded (for example, Davis, 1980), these rocks and those of neighboring canyons became one of the best examples in the world of a "metamorphic core complex" (see also Saguaro National Park East).

The main purposes of this trip are to acquaint the traveller with (1) the form of some large intrusions of formerly molten or igneous rock now cooled and solidified, (2) the effects of recrystallization and shearing to form a new rock called "mylonitic gneiss," (3) some faults and folds that formed later, and (4) more recent processes that cut the canyon itself.

The intrusions are light-colored granitic rocks of Eocene age (about 50 million years). Granite is a coarse-grained igneous rock consisting mostly of feldspar and quartz. In this area the Eocene granites form sills, i.e. intrusions that parallel the structure of surrounding older rock or host rock. In this canyon, one granite sill, about 250 m (800) feet thick, forms the cliff-like upper canyon walls; two others can also be seen.

However, both the Eocene granites and their host rocks have been severely deformed and partially recrystallized in this canyon and throughout the Catalina forerange. The deformation was a response to stretching of continental crust in the southwestern U. S. about 25 million years ago. Rocks in this canyon, because they were at considerable depth in this crust (about 6 miles) at that time, were hot enough for many (but not all) of the constituent mineral grains to deform in plastic or ductile manner. Such deformation allowed this deeper portion of crust to respond to stretching by delamination into thinner packages. The platy rocks so deformed are called mylonitic gneisses, and partially define a metamorphic core complex. Rocks stretched at shallower crustal levels in brittle conditions form detachment faults (see p.).

Lower Sabino Canyon (upstream as far as Sabino Basin) transects the forerange part of the Santa Catalina Mountains. Rocks similar to those described here are found also in Bear, Pima, and other forerange canyons. Other parts of the Catalinas are described with the Catalina Highway trips. A lengthy description of rocks in this region is given by Force (1997).

Logistically this trip is done most easily on the shuttle, but it can be done on foot. The stops are located mostly by shuttle-stop number. The trip requires at least half a day, preferably a cool day.

A1 – Mylonitized mixture of igneous rocks

Lower Sabino Canyon has become a famous locality for mylonitic deformation. Mylonitic gneiss can be seen at any place along the canyon upstream as far as Sabino Basin. A particularly good spot is shuttle stop 2. The photograph (fig. A1-1) shows what mylonitic rocks look like near here.

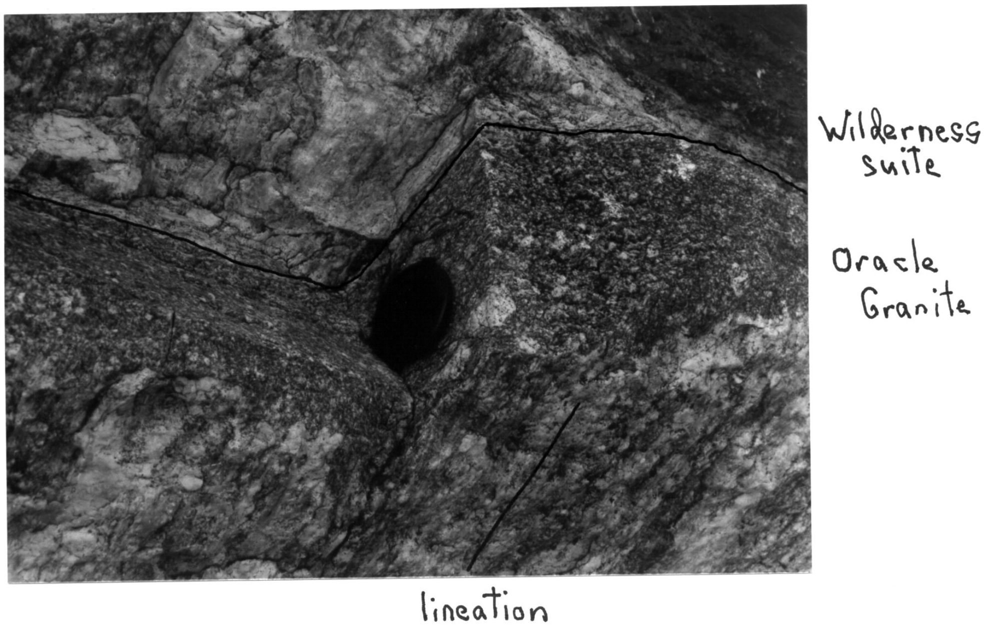


Figure A1-1. Annotated photo of mylonitic gneiss derived from Oracle Granite and Wilderness intrusive suite parent rocks, showing lineation, foliation (parallel to contact), and shear couple

Mylonitic rock is the flattened platy rock type of this area. Note that some mineral grains (mostly chalky white feldspar) have a crushed and rolled appearance, but that others (mostly gray quartz) look drawn out like wire. These result from brittle and ductile shearing, respectively. This combination of mineral behaviors is characteristic of mylonitic gneiss.

Two types of rocks were deformed together to become mylonitic in this canyon. The darker rock (fig. A1-1) is older, mostly Oracle Granite of Precambrian age (1.4 billion years). That is, its age, general mineralogy, and chemistry are the same as the granite around Oracle, Arizona, which looks quite different at first glance (see fig. C10-2a). Intense deformation can do that. The light-colored rocks are granites and pegmatites (very coarse granites; see C7, C10) of Eocene age (about 50 million years), much younger than Oracle Granite.

The rocks became mylonitic about 25 million years ago, at about 300^{o} C. (or 600^{o} F.)-- hot enough for quartz but not feldspar to be ductile. The rocks were about 6 miles deep. The shearing here reflects the rocks at the top of the stack moving about one mile toward the southwest relative to rocks at the bottom. Visualize rocks on the canyon skyline having moved toward Tucson relative to you as the mylonitic fabric was forming. The lineation, or linear part of this fabric defined by drawn-out quartz (see fig. A1-1), is in the direction of movement.

The platy nature of mylonitic rocks coupled with the undulating shape of bounding detachment faults has imparted a streamlined shape to this part of the Catalinas (fig. A1-2), and to some other metamorphic core complexes.

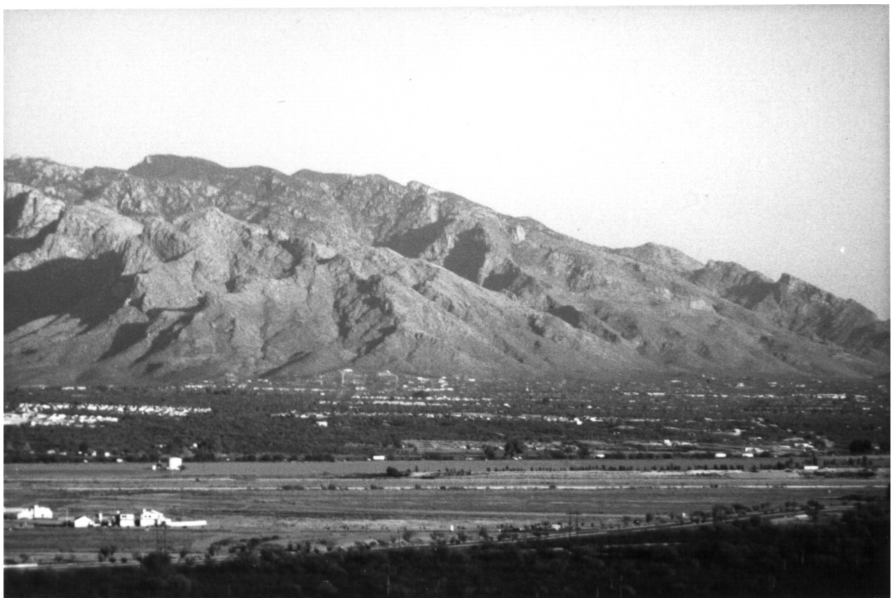


Figure A1-2. Photo of topographic expression of Catalina mylonitic rocks, from the west end of the range

A2 - Intrusive sills

Igneous features in this canyon are best represented by three thick sills of light-colored granite. At about milepost 2.6 between shuttle stops 6 and 7, one is standing on the lowermost intrusive sill of the Catalinas (the Seven Falls sill). Most of the cliffs on the upper valley walls forming the skyline on both sides are formed by the next lowest (the Gibbon Mountain sill). Thimble Peak itself is a small remnant left by erosion of a large third sill (the Thimble Peak sill). The sills are of light-colored granite. Between the sills is the older dark-colored banded rock that the sills intrude. Figure A2-1 shows the Seven Falls and Gibbon Mountain sills from here.

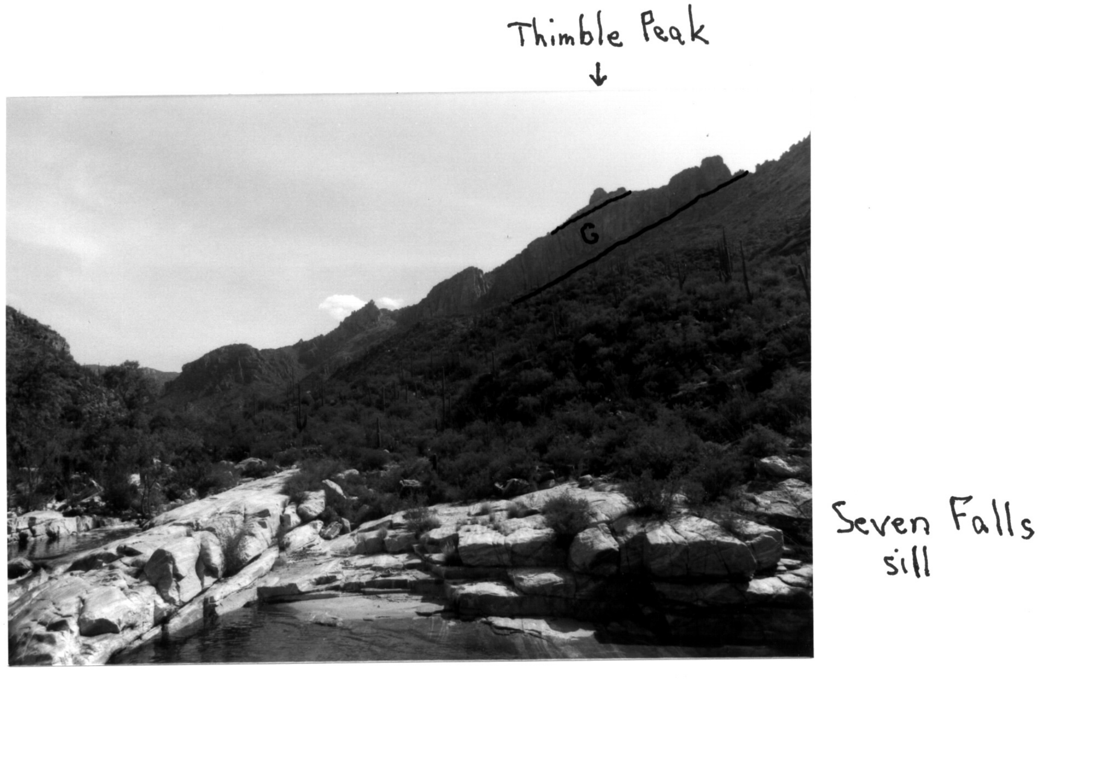


Figure A2-1. Annotated photo of Seven Falls sill, showing Gibbon Mountain sill (G) and Thimble Peak in the background

All three sills are of light-colored granite of Eocene age (about 50 million years), intruded mostly into Oracle Granite of Precambrian age (1.4 billion years). Both were later mylonitically deformed together (see A1), but the original form of the intrusions can still be discerned. The intrusions here are called sills because they are parallel to an unconformity or buried erosion surface at the top of Oracle Granite (not visible from here; see stop C10).

We do not know the thickness of the Seven Falls sill at our feet because its base is nowhere exposed. The Gibbon Mountain sill is 240 m (800 ft) thick near here. The Thimble Peak sill is 800 m (2600 ft) thick, but only the base is visible from here (see C1 for top). Even thicker sills of similar rock occur in the Catalina main range (C2, C3). All these sills together are called the "Wilderness intrusive suite". They are more resistant to erosion than the host rocks, which form vegetated slopes.

The reason the intrusive granites formed parallel sills is unclear, because there is no obvious parallel direction of weakness in the Oracle Granite host rock. Sill intrusion has the interesting effect of expanding the original host-rock sequence, somewhat like insertion of new paragraphs in older text on a word-processor. Like the text, the rock sequence may be so expanded it no longer makes sense (fig. A2-2).

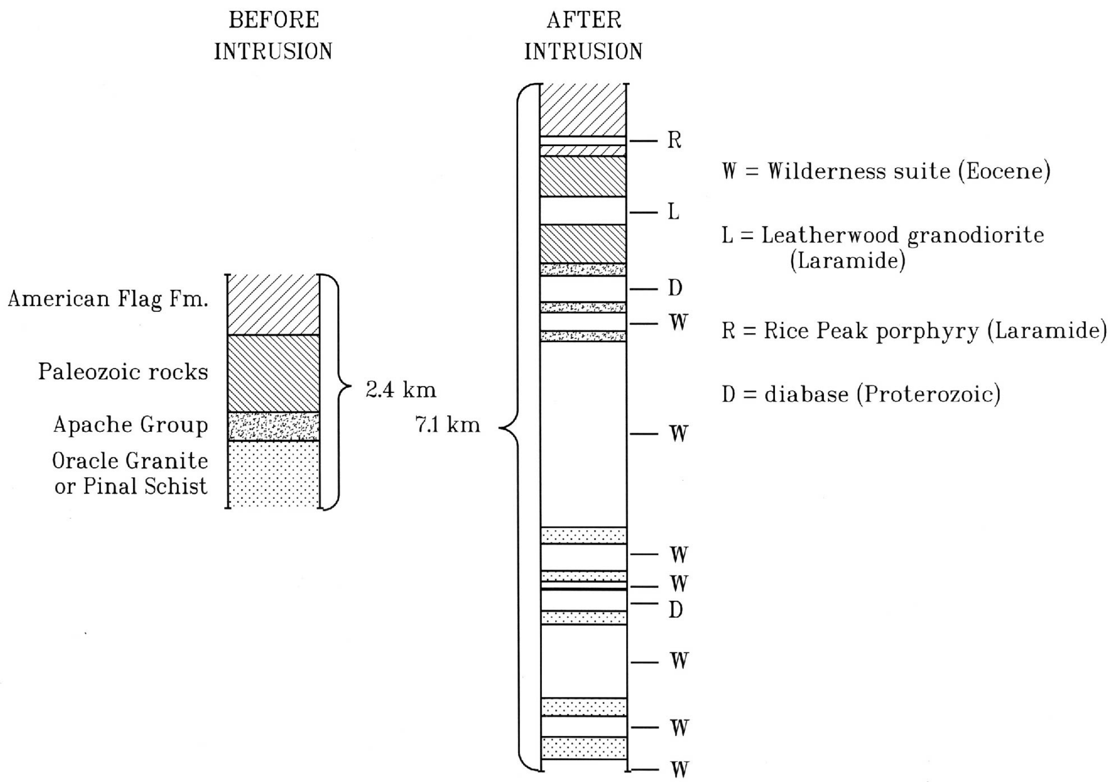


Figure A2-2. Diagram of original sequence of rocks, and same sequence after sill intrusion

Light-colored Eocene granites of the Wilderness intrusive suite are also found in the Rincon and Tortolita Mountains. They were described in greater detail by Keith and others (1980).

A3 -- Fault and anticlinal fold

These structures can best be seen at about milepost 1.1, before shuttle stop 1, just downstream of the confluence of Rattlesnake tributary, where the view is that of figure A3-1. This photograph shows the trace of the fault up-canyon away from the viewer, and the arched shape of the intrusive sills (A2).

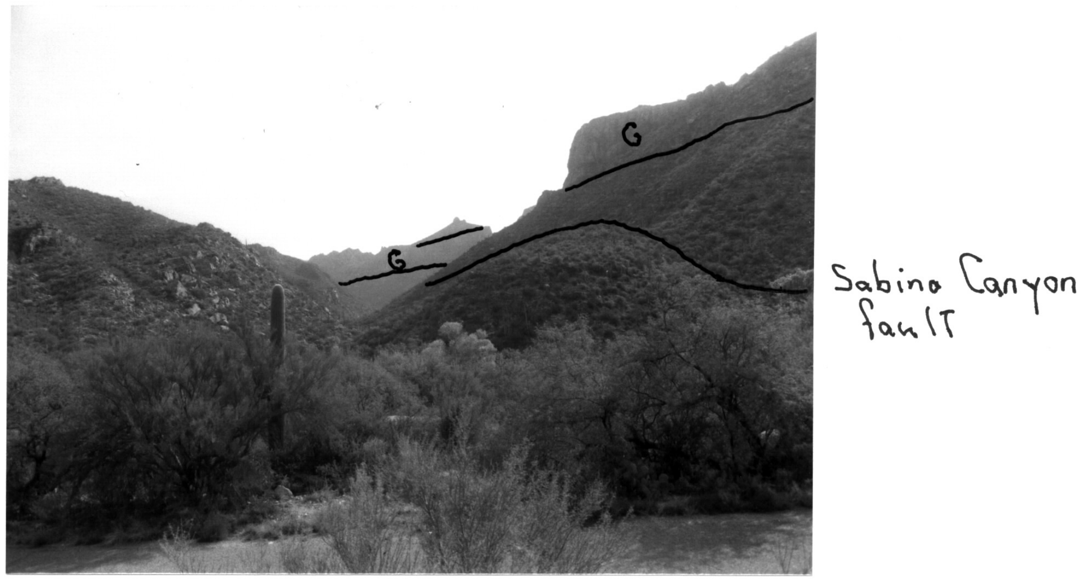


Figure A3-1. Annotated photo of Sabino Canyon fault trace and Gibbon Mountain sill (G).

A fault is a subsurface fracture that has moved the rock sequence on one side of the fracture relative to the other (fig. A3-2). In this case we are standing (more or less) on one branch of the Sabino Canyon fault, which trends up-canyon, slightly upslope to the southeast of the streambed. The fault plane itself is poorly exposed -- a common case because fractured rocks are susceptible to rapid erosion. The course of Sabino Canyon follows the fault for this reason.

Figure A3-2. Diagrams of faults. Gouge is found along fault plane. A. Gently dipping normal fault, with motion like that of a detachment fault. B. Thrust or reverse fault.

Motion on the Sabino Canyon fault is revealed by the differing levels of the Gibbon Mountain sill (A2) on either side of the fault -- on the southeast (right) side the sill forms the skyline cliffs of Saddleback, whereas on the northwest side the base of this sill is at our level (the small "cave" visible from here is at the base of the sill). The fault must have moved down about 150 m (500 ft) on the northwest side in this area.

On the slope behind the road, blocks of fault breccia like that of figure A3-3 are found. Fault breccias form in the plane of the fault and are mixtures of angular blocks plucked from both walls in a matrix of pulverized rock (called gouge) formed by the grinding motion of the fault. The gouge here is pink. The blocks of fault breccia we see on the slope have eroded out from outcrops of the fault plane in the rocks above.

Figure A3-3. Photo of fault breccia in Sabino Canyon fault

An anticline is an arch-shaped fold. The arched form of the sills visible from here is a result of folding on the Forerange anticline. We are on the southwest limb or side of the fold; Thimble Peak is on the northeast limb (fig. A3-1). The crest of the fold trends northwest-southeast along the length of the Catalina forerange; that is, it crosses Sabino and other forerange canyons. The folding here is rather subtle.

Both fold and fault are part of the later history of the forerange, having formed only about 20 million years ago. However, the fault is no longer active and presumably poses no earthquake danger.

A4 -- Canyon cutting

Processes of canyon cutting have produced our scenery here, and can be easily visualized. The main processes, down-slope movement and erosion, can be seen all along the canyon. Down-slope movement is best seen near shuttle stop 7 and milepost 3, where an old landslide or fan containing enormous blocks of rock is found on the southeast side. Figure A4-1 shows a similar slide on the northwest side. Erosion by Sabino Creek is more apparent elsewhere, as near shuttle stop 2, where the floods of January 1993 left a record.

Figure A4-1. Photo of tree in Sabino Creek. Plant debris suggests the severity and water level of recent flood.

Canyons are cut by the streams in them. Several stages in the process can be seen along the canyon. One is the downslope movement of debris from the steep walls by several processes in which gravity plays a part. Near shuttle stop 7, note the jumbled attitudes of the blocks and their random sizes in the deposits mantling the slopes on both sides (fig. A4-1). It is unclear whether this deposit formed in a few minutes (as a rock avalanche or catastrophic landslide) or many years (either as a slower landslide moving as a body or a colluvial fan accumulating block by block from the cliffs above).

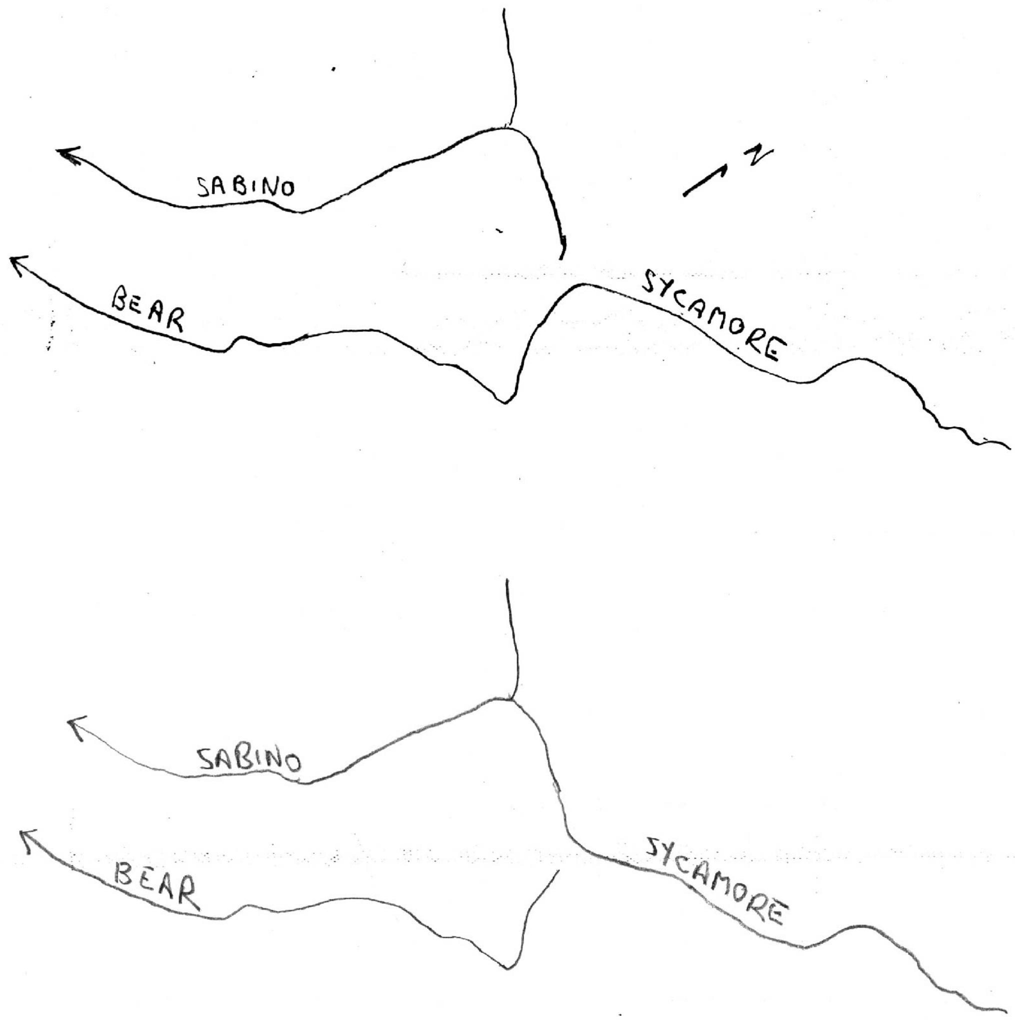
Outside this deposit, blocks are travelling slowly downslope partly by frost wedging. Moisture under the block expands when it freezes, pushing the block off its base. When thawing occurs, the block returns to a new base a tiny distance downslope.

The next stage of canyon cutting is removal of this debris by the stream. If not removed, the debris would eventually accumulate in the canyon and partly fill it in. However, the stream has cut entirely through the landslide-fan deposit into bedrock, showing the power of the stream to move large blocks out of its bed and downstream. Movement distance may be modest, but repeated small movements eventually round or break up the blocks. Eventually the material in these blocks is washed into the Tucson Basin.

Those fortunate enough to visit soon after a flood may get a vivid glimpse of stream power. In January 1993, truck-sized blocks were moved, as shown afterward by rotation from their original attitudes. Figure A4-2 shows high-water marks of these floods near shuttle stop 2.

Figure A4-2. Photo of landslide-fan deposit on the *northwest* slope of Sabino Canyon

Another aspect of canyon-cutting is not apparent here in the canyon bottom. This is headward erosion, the lengthening of the canyon by erosion in the headwaters. A stiff 3-mile hike up the east fork of Sabino Canyon brings one to a site of imminent stream capture or stream piracy-- the east fork eroding headward will encounter the bed of Sycamore Canyon, a tributary of Bear Canyon (fig. A4-3). The waters of Sycamore Canyon will then flow into Sabino Canyon, which will have effectively been lengthened (in this fork) 8 km (5 mi) in a single event.



A4-3 Diagram of potential stream capture

The ages of geologic features in Sabino Canyon range from 1.4 billion years to 20 million years. In contrast, canyon-cutting is a process occurring today and influencing life down in the Tucson Basin.

Bibliography

Davis, G. H., 1980, Structural characteristics of metamorphic core complexes, southern Arizona, *in* Crittenden, M. D., Coney, P. J., and Davis, G. H., eds., Cordilleran metamorphic core complexes: Geological Society of America Memoir 153, p. 35-77.

Force, E. R., 1997, Geology of the the Santa Catalina Mountains, southeastern Arizona: a cross-sectional approach: Monographs in Mineral Resource Science #1, 135 p.

Keith, S. B., Reynolds, S. J., Damon, P. E., Shafiqullah, Muhammad, Livingston, D. E., and Pushkar, P. D., 1980, Evidence for multiple intrusion and deformation within the Santa Catalina-Rincon-Tortolita crystalline complex, southeastern Arizona, *in* Crittenden, M. D., Coney, P. J., and Davis, G. H., eds., Cordilleran metamorphic core complexes: Geological Society of America Memoir 153, p. 217-267.

PARTS B AND C: CATALINA HIGHWAY

INTRODUCTION

Tucsonans are seldom out of sight of the Santa Catalina Mountains and many relax there using the Catalina Highway for access. Some are curious about the geologic features of these mountains. Therefore we devote two trips in this guidebook to the Catalina highway.

Rocks of the Catalinas range in age from about 1.4 billion to 20 million years, whereas uplift to form the present mountain range began about 20 million years ago. Precursor mountain ranges also rose here about 70 million years ago.

The record of uplift mostly consists of erosional debris found in adjacent basins. In the range itself we see eroded remnants of uplifted (and generally tilted) continental crust. Originally this consisted of Precambrian Oracle Granite (about 1.4 billion years) overlain by sedimentary rocks of Precambrian through Cretaceous age (1.4 billion through 70 million years). Igneous rocks were intruded at about 1.1 billion, 70 million, and 50 million years (Keith and others, 1980), and the rocks were metamorphosed mostly at about 70 million years, except where they were mylonitized at the south end of the range at about 25 million years. The cause of the following uplift is still a matter of debate, but certainly involves detachment faulting and gravitational equilibrium of the mountain mass in the earth's crust. Some of these terms are defined in trip A and the following stop descriptions.

On the trips we will see igneous rocks, faults, and metamorphic rocks of two types. Mylonitic metamorphic rocks are in trip B, whereas more conventional metamorphic rocks are in trip C. Trip B is more suitable for cool days, trip C for summer. Trip B requires at least a half day, trip C a whole day. The stops are by the highway, so any vehicle will suffice, but a few minutes walk is required for some stops. The stops are described in the order they are encountered as one ascends.   Navigation is partly by mileposts along the highway that are only in whole miles, so some odometer work is required.

For readers that would like to extend their observations to the trail networks in the Catalinas, Force (1997) contains locality descriptions and geologic maps. His descriptions are technical.

Ascending the Catalina Highway is of course a botanical field trip too. At the base of the mountain we see a saguaro-ocotillo desert. At elevations of about 4000 feet near milepost 6, these desert assemblages remain on south-facing slopes but are replaced by live oak-manzanita scrublands on north-facing slopes. At elevations of about 6000 feet near milepost 11, a similar transition to ponderosa pine forest occurs. On the highest parts of the range, north facing slopes and riparian areas contain fir, spruce, and maple trees.

PART B. LOWER CATALINA HIGHWAY

This trip is partly in the Catalina forerange (like trip A) and partly in the south face of the main range. Along the Catalina highway, the boundary between forerange and main range is at Molino basin. As mylonitic rocks are described in greater detail for the Sabino Canyon (trip A) stops, the reader may want to consult that section.

The lower Catalina Highway is constructed in less resistant host rocks between the large intrusive sills (stop A2), so those can be seen only from afar as at stop B3 along the highway.

B1 - Mylonitized igneous rocks, fold, and cross-cutting relationship

Mylonitic rock can be seen at any place along this part of the highway; such rocks characterize the forerange. In a few places, some features are apparent that are not at otherwise-similar stop A1. Stop B1 at milepost 3.7 is especially good as a fairly safe area to stop and as a viewpoint for large-scale features in mylonitic rocks. Figure B1-1 shows these features in nearby road cuts, and figure B1-2 shows them across Molino Canyon.

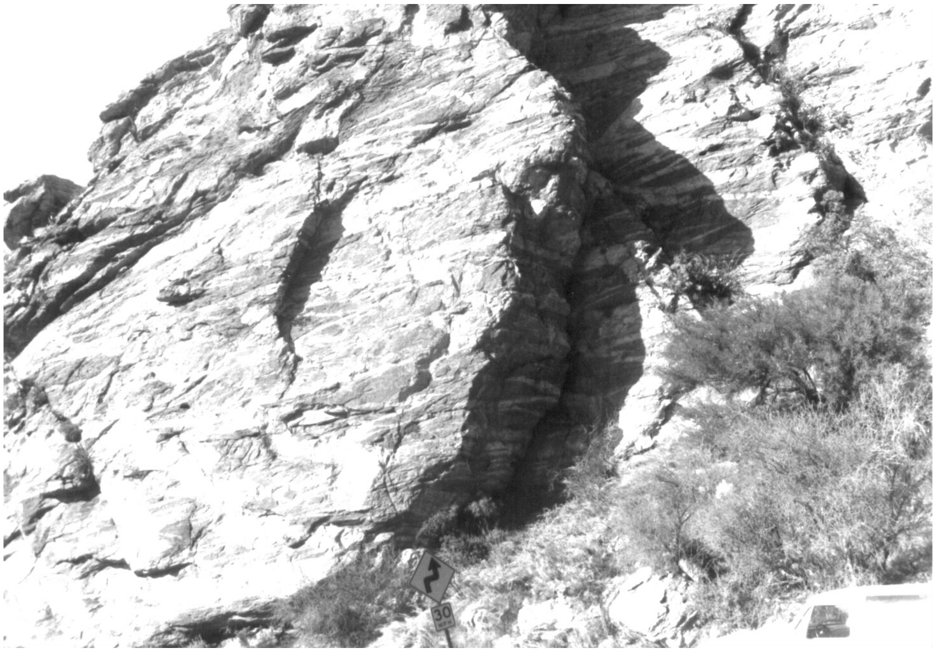


Figure B1-1. Photo of down-lineation view of mylonitized dikes and sills, Molino Canyon

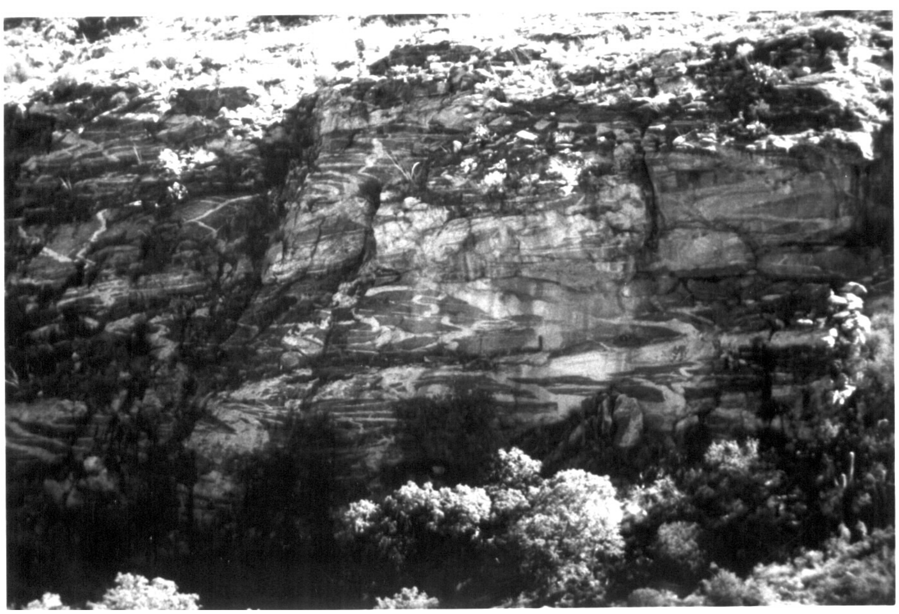


Figure B1-2. Photo of same rocks across canyon, showing folds visible in a cross-lineation view.

The same rocks types are present here as at stop A1, to which the reader is referred. Older dark-colored Oracle Granite and younger light-colored granite and pegmatite of the Wilderness intrusive suite (all igneous rocks) were deformed together to form platy mylonitic gneiss (fig. A1-1).

At this stop, the steep walls of Molino Canyon show large-scale features resulting from mylonitic deformation (figs. B1-1 and B1-2). The igneous intrusions represented by the light-colored rocks originally formed an array of sills and dikes, i.e. intrusions parallel or at a high angle to host-rock structure, respectively (fig. C7-1). This array has been flattened and folded during mylonitic deformation. Figures B1-1 and B1-2 show different views of these folds, parallel and perpendicular to lineation (stop A1), respectively.

Also visible from here is the Forerange anticline, a gentle arch-shaped fold (as at stop A3). At this stop we are near the crest of the fold, so that mylonitic fabric dips down away from us in both directions (northeast and southwest) along the canyon.

The strange contrast in rock color in a road cut just down-canyon is along a weathered dike (as at B2) in mylonitic host rocks. The dike has not been deformed, and this cross-cutting relationship provides evidence that the dike was intruded after mylonitization had ceased.

B2-- Relation of mylonitic fabric to main range

The spatial relation of the mylonitic fabric to the main range is apparent near Molino Basin. A pullout by an attractive waterfall (commonly dry) is across from a large roadcut and below the tollbooth just below Molino Basin (milepost 5.2). Figure B2-1 shows the exposed rocks, including a weathered dike.

Figure B2-1. Photo of mylonitic Leatherwood granodiorite (dark) and Wilderness intrusive suite granite and pegmatite (light), both cut by undeformed dike

The rock assemblage here is mylonitic, as at stops A1 and B1. However, here we are on the northern side of the Forerange anticlinal fold, so that the mylonitic fabric dips down to the northeast. Note that this plane if extended would clearly *underlie* the main range to the north (fig. B2-2; Reynolds and Lister, 1990). A fault zone is present in Molino Basin but does not change this relation.

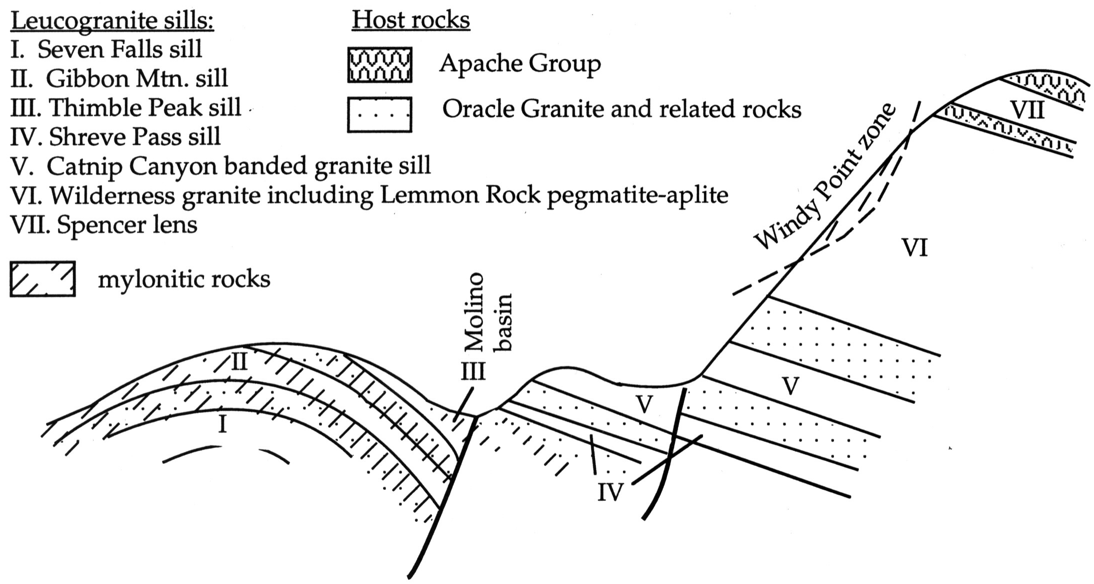


Figure B2-2. Diagram of Wilderness intrusive suite sills and mylonite in cross-section

The older dark mylonitized rock here is Leatherwood granodiorite rather than Oracle Granite. The Leatherwood is about 70 million years old, and intrudes much older Oracle Granite nearby. Both were then intruded by light-colored granites and pegmatites (C7, C10), and this whole rock assemblage mylonitically deformed together. The dark dike (fig. B2-1) is not deformed, so we know it was intruded after mylonitization ceased.

Complex? Well, yes, but you can put the puzzle together bit by bit with the evidence you've seen, just as the geologists have.

B3-- Igneous inclusions and intrusive sill

Unmelted inclusions of older host rocks are a characteristic feature of igneous rocks. Inclusions of dark-colored Oracle Granite in light-colored granite and pegmatite are common on the stretch of highway from about milepost 5.8 to 6.2. Figure B3-1 shows their appearance in road cuts. Figure B3-2 shows the large intrusive Gibbon Mountain sill across Molino Basin from here.

Figure B3-1. Photo of inclusions in road cut near milepost 5.8

Figure B3-2. Annotated photo of Gibbon Mountain sill in Molino Basin, taken looking west from near milepost 6.0

Inclusions (also called xenoliths by geologists wishing to appear erudite) are unmelted fragments of older rock in a younger igneous rock. At this stop, dark-colored Oracle Granite and similar rocks, "float" in light-colored granite and pegmatite (C7, C10). Some of the inclusions are cigar-shaped, and some arrays of cigars are nearly parallel. All the rocks are somewhat deformed by later mylonitization. .

From here one looks south across Molino Basin (fig. B3-2), which is in part etched along the Romero Pass fault zone of stop B4 and its weakened wallrocks. Across the fault is the Gibbon

Mountain sill of light-colored granite (as at stop A2), dipping north. Its base is so nearly parallel to the north-facing slope that erosion has peeled off part of it along an irregular trace (fig. B3-2). The sill does not extend to where we are standing because it is cut off by the faults in Molino Basin.

B4-- Fault and fault gouge

One seldom gets to examine the plane of a fault, but a road cut through a saddle near milepost 7.3 exposes gouge and other crushed rock of the Romero Pass fault zone. Park at the entrance to the old prison camp at about 7.4. Figure B4-1 shows what the gouge zones look like; they include green, red, white, or black veined clayey rock among wall rocks that are themselves shattered.

Figure B4-1. Photo of fault gouge forming entire roadcut near milepost 7.4

This stop exposes many thin zones of gouge, or finely pulverized rock. The color of the gouge zones generally ranges from green to rusty red, but a variation is bleached white with local black stains of manganese. The planes defined by the gouge zones vary in orientation, also. The wall-rocks of gouge are light-colored banded granites that are themselves crushed or shattered.

Rocks of the Catalina forerange are everywhere separated from those of the main range by the Romero Pass fault zone (see A3 for other faults). The crushed rocks formed as this fault moved, about 21 million years ago. The south side apparently moved upward several hundred feet, then both sides were eroded. Weakened rock along this fault zone now forms a succession of valleys and saddles, such as Sabino and Molino Basins (fig. B3-2) and Shreve Saddle and Romero Pass, respectively. The saddle at this stop is along just one branch of this fault zone.

B5 -- Overview of granitic sills, fold, and faults

Near milepost 8.5 are small pullouts including Thimble Peak Vista where one can see back into the forerange. This time we are seeing Thimble Peak from above (fig. B5-1; compare with fig. A2-1).

Figure B5-1. Annotated photo of Thimble Peak area from Catalina Highway showing sills and Romero Pass fault zone. The sills (not outlined) below the Thimble Peak sill (T) are the Gibbon Mountain and Seven Falls sills.

This is one of the best spots to see the shape of the granitic intrusions that form much of the Catalina forerange. The granitic bodies shown in figure B5-1 are sills, or intrusives parallel to the structure of their host rocks. They belong to the Wilderness intrusive suite of granitic rocks of Eocene age (about 50 million years old). The two sills visible from here are the Thimble Peak and Gibbon Mountain sills, which were described from below at stop A2. The Gibbon Mountain sill forms the cliffs above Bear Canyon. The Thimble Peak sill has been eroded away along much of the ridge above; its base forms Thimble Peak itself, but its entire thickness is exposed to the right (north).

Both the granitic sills and their host rock, the Oracle Granite (1.4 billion years old) were deformed to mylonitic gneiss after solidification, but this has not disrupted the form of the sills too severely.

The sills have been arched upward in the Forerange anticline (see A3). From here the northern (right) part of the anticline can be seen; note that the Thimble Peak sill dips rather steeply into the Sabino Basin (fig. B5-1).

Also visible from here are several branches of the Romero Pass fault zone (see B4) that separate the forerange from the lower parts of the main range, where we stand. Because of these faults, it is difficult to match the sequence of rocks to the south (left) with those to the north (right). It is thought that the forerange moved up relative to the main range, contrary to the present configuration of the land surface.

The granite body through which the highway is cut here is the banded granite of stop C1. The relation of the sills in the forerange and the main range is shown by figure B2-2.

PART C. UPPER CATALINA HIGHWAY

Along the upper part of the Catalina Highway we will focus less on mylonitic rocks and faults, and more on granitic rocks with their variations and on conventional metamorphic rocks, i.e. rocks recrystallized at high temperature. The metamorphic rocks are the host rocks along the roof of the granitic intrusions.

C1 -- Intrusive contact, banded granite and inclusions

Intrusive contacts of the big sills of light-colored granite are exposed in only a few places on the highway. Where the highway turns into Bear Canyon, overlooking Seven Cataracts, is a pullout near milepost 9.2. On the south (right) side of the road is a contact between a finely banded granite below, and an inclusion-choked granite above (fig. C1-1).

Figure C1-1. Annotated photo of contact between banded granite and inclusion zone at Seven Cataracts overlook

Two rock types are exposed in contact here (fig. C1-1). The underlying body, exposed from here all the way back to B5, is a banded granite called the Catnip Canyon sill. Catnip Canyon itself is at milepost 8.8, sometimes called Deadman's Curve; we won't stop there.

The banding (fig. C1-2) appears to be an original feature of the rock, though locally it has been deformed or intruded by younger granite. Where the banding is marked only by differences in the relative abundance of minerals and/or changes in their grain size, the banding may have been due to mineral settling in the magma chamber or to crystallization along its roof or floor.

Since the banding is parallel to the margins of the sill, and since the slight dip of the sill is the same as that of older sedimentary rocks of the region, the banding must have been nearly horizontal when it formed. Locally, upper banding cuts lower banding (fig. C1-2), but the origin of this relation is controversial.

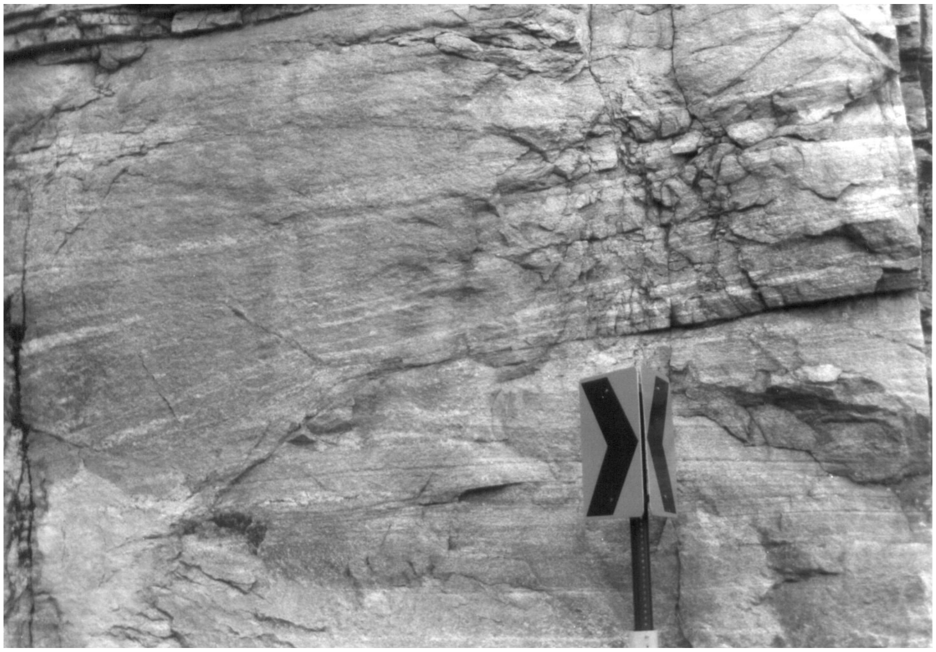


Figure C1-2. Photo of banding in Catnip Canyon sill, showing truncation

The rock above the contact is exposed along the highway to about milepost 10.0 and is the same as at B3. This unit is a mixture of older dark-colored rocks and small lighter-colored sills and dikes related to two big sills of the Wilderness intrusive suite, the Catnip Canyon banded granite sill below and the Wilderness sill above (fig. B5-2). The older rock, forming inclusions at the contact itself, is mostly Oracle Granite (1.4 billion years old). Thus the contact is intrusive, with the banded granite below intruding deformed Oracle Granite above, but is complicated by other granites.

About 260 ft east along the road (watch for cars!) is a dark inclusion of diabase, or medium-grained iron-rich igneous rock, here of Precambrian age (1.1 billion years old). It is intruded by later granite (fig. C1-3). Within the inclusion is a folded banding, characteristic of some metamorphic rocks, that is cut by granite dikes, suggesting that this diabase had already suffered much deformation and recrystallization *before* the granites intruded.

Figure C1-3. Photo of diabase xenolith; the current roadbed comes partway up this exposure.

Look across the canyon to the opposite wall. Now that you are familiar with the rocks above and below the contact on the road, you may be able to trace the contact through the cliffs.

C2 -- Garnet granite

Garnet granites are somewhat unusual, but there are cubic miles of them in the Catalinas. This stop is Hitchcock camp, well marked at milepost 12.0. The safest good exposure of garnet granite is on the north side of the spur road to the camp right by its junction with the highway.

This is the least deformed area of granite of the Wilderness sill (fig. B5-2), the thickest sill of the Wilderness intrusive suite at about 2 km or 1.5 mi. We will see pegmatite (very coarse-grained granite) bodies at the top of this same sill at the range crest (C7, C10). The steep south-facing escarpment of the range from near milepost 10.0 to the top consists almost entirely of this one sill.

This granite is somewhat unusual. It contains almost no dark minerals such as biotite mica that give many granites their salt-and-pepper appearance. Instead due to its high aluminum content, it contains the white mica <u>muscovite</u> and small amounts of deep red <u>garnet</u>. The garnet crystals range in size up to about 1/4 in or 5 mm, but can be much finer (as at C9). The crystals may look almost spherical, but reflect light off their crystal faces (fig. C2-1). Few other minerals in this rock are perfect crystals; garnet may have shouldered its neighbors aside as it grew. Garnet is so hard and tough that it persists as grains in the beds of streams draining this sill, right to the foot of the range. They are collected there as "sand rubies," a misnomer.

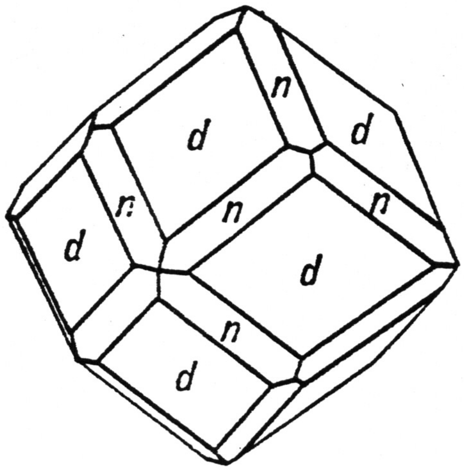


Figure C2-1. Diagram of garnet crystal

C3 -- Mylonitic granite and rock palisades

This stop is scenic Windy Point, well marked near milepost 14.0. Part of the stop is about 200 feet along the ridge to the west. Probably hundreds of geologists have been taught to "read" mylonitic rocks at Windy Point.

Few rocks this high in the main range are mylonitically deformed (see A1, B1 for description) -- we saw mylonitic rocks pass *under* the main range at B2 (fig. B2-2). However, a tongue of a higher mylonite zone skims the surface of the main range, and Windy Point is one place where it touches down.

We are still in the Wilderness sill (fig. B5-2) at Windy Point, so this mylonite is made from granite like that of C2, which is directly below us to the southeast here. The quartz (gray) has been flattened and drawn into horizontal rods trending NE-SW, whereas the feldspar (chalky white) has been rolled, fractured, and sheared off in a plane dipping southwest. This implies that upper rocks must have moved southwest relative to lower rocks (fig. C3-1), as at stop A1.

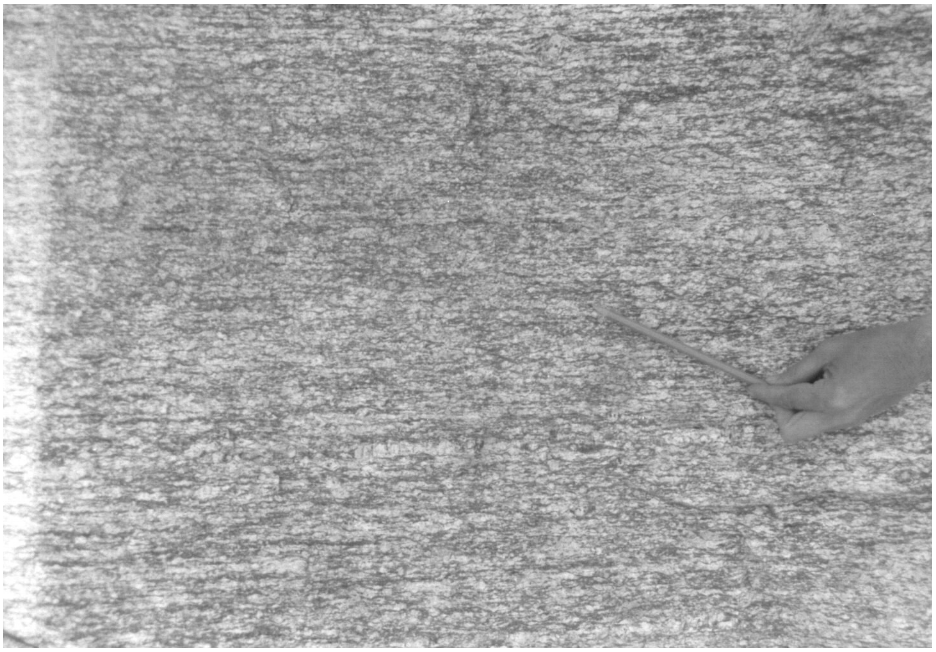


Figure C3-1. Annotated photo of Windy Point mylonitic granite showing flattening surface and shear direction (lineation)

West of the lookout is similar mylonitic granite. As you look northeast (fig. C3-2) along the lineated quartz rods (fig. A1-1), all the hills that intersect this lineation except Barnum Rock consist of mylonitic granite, right to the skyline at Leopold Point. All the valleys below it and all the hills to the side (like Rose Peak and Lizard Rock) consist of granite that is little-deformed. Thus one can see much of the evidence for the tongue-like shape of the Windy Point mylonite zone from here. Barnum Rock is apparently formed by a younger granite that was intruded after mylonitization ceased (C4).

Figure C3-2. Annotated photo of lineated mylonitic granite (arrow in foreground shows direction) and extent of Windy Point mylonitic zone on the skyline

The great rock palisades such as those near Windy Point occur in a band around the south face of the main range, where the rock type is everywhere slightly deformed Wilderness granite. The palisades themselves are outlined not by the mylonitic fabric, which is nearly horizontal, but by vertical fractures or joints.

C4 -- Overview of stratigraphy and structure

This stop is San Pedro Vista, which is well marked near milepost 17.5. It serves as a geologic as well as a scenic overlook. From here one can look northeastward into the remote backside of the Catalinas and the San Pedro Valley (fig. C4-1).

Figure C4-1. Annotated photo from San Pedro Vista to the northeast, showing zone of thrust faults

From San Pedro Vista, the view includes the northeastern part of the Catalinas, accessible only by trail. The stratified rocks visible from here include (from the base) Precambrian and Paleozoic sedimentary rocks (fig. C4-2). Also visible are <u>thrust faults</u>, gently dipping faults that result from compression, placing older stratified rocks over younger ones, contrary to the normal order and unlike detachment faults. In this case, Precambrian rocks and Cambrian Bolsa Quartzite (forming the prominent white cliff) have been thrust above younger Cambrian Abrigo Formation (fig. C4-1). The Edgar thrust fault, one of the structures responsible, is marked by reddish soils.

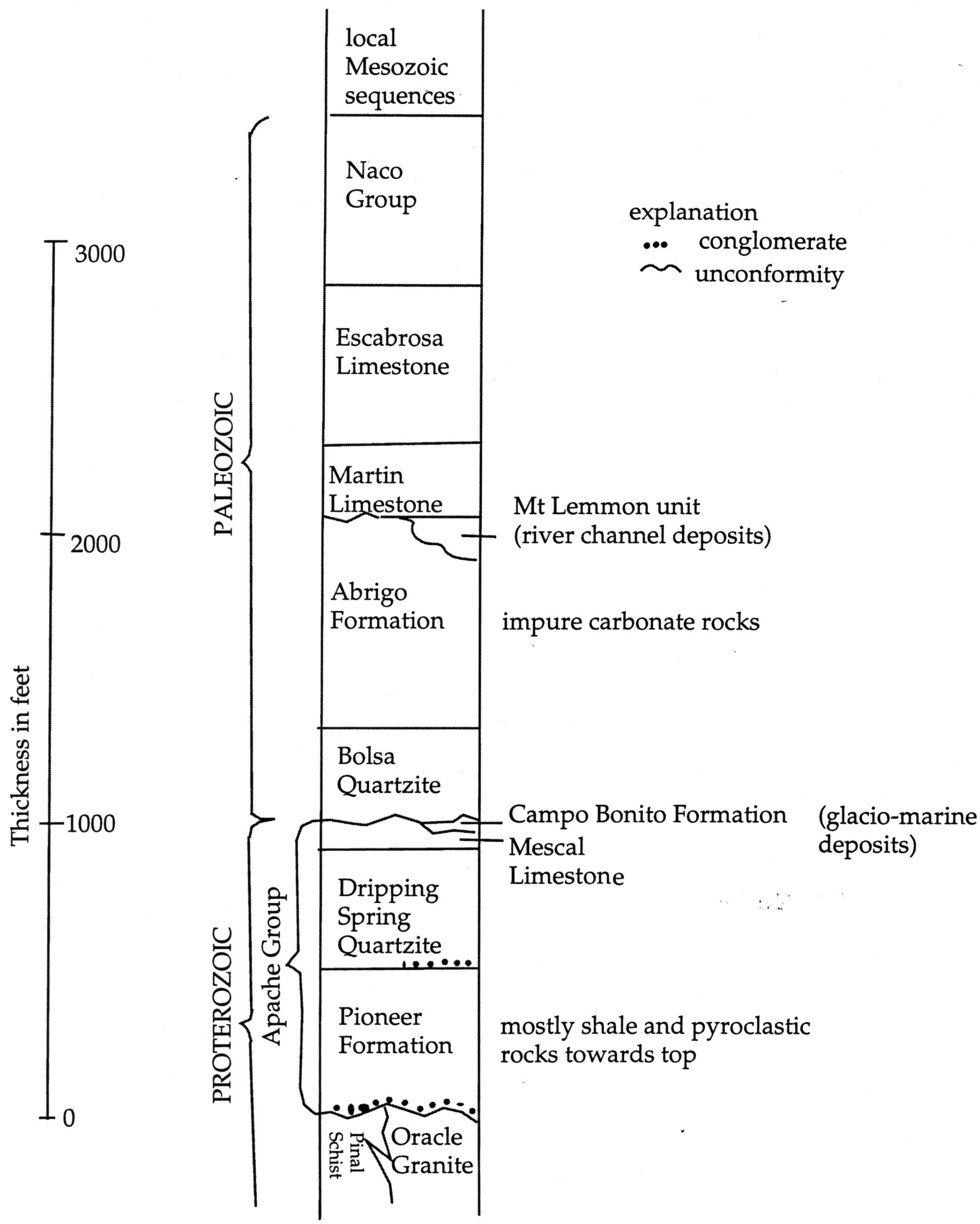


Figure C4-2. Diagram of rock sequence where undeformed

Also from here one can see the Knagge granite, whose age is uncertain but apparently younger that the Wilderness intrusive suite; it is probably about 25 million years old. It forms some of the cliffs near the overlook as well as those of Barnum Rock (fig. C3-2), where it has apparently intruded mylonitic rocks of the Windy Point zone. The Knagge granite contains garnet and muscovite, like the Wilderness sill, but also contains abundant biotite.

C5 -- Thrust fault and metamorphic rocks

As the highway enters Bear Wallow near milepost 22.0, a road cut exposes the Bear Wallow thrust fault (fig. C5-1), dipping gently southeast, from the road level to about 3 m above it.

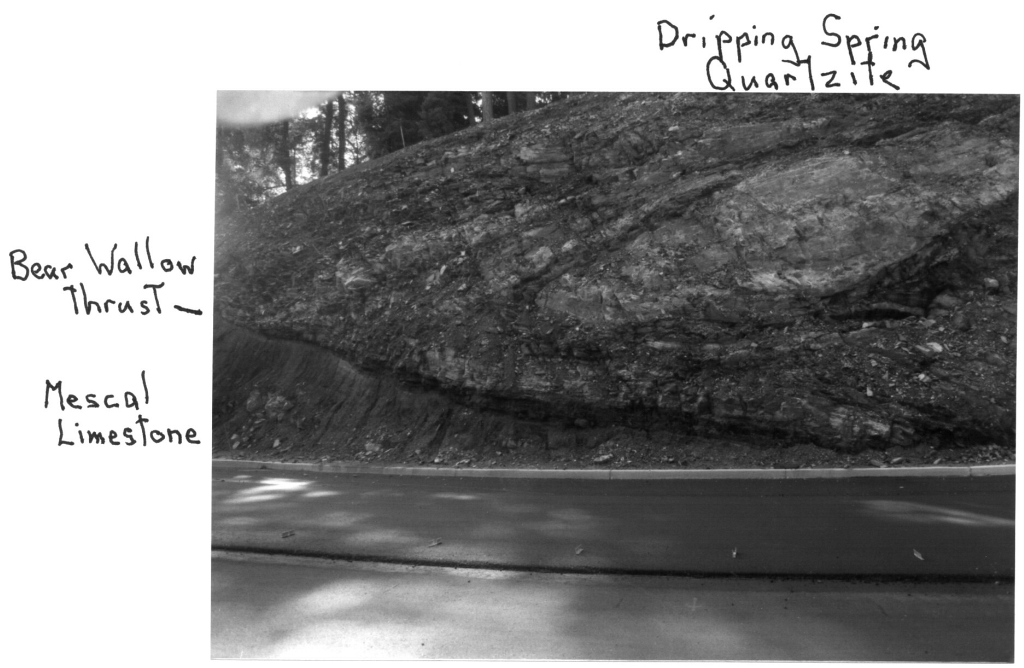


Figure C5-1. Annotated photo of Bear Wallow thrust

This exposure (unlike C4) is our chance to see a thrust fault up close. In this case the rock above is the Dripping Spring Quartzite, and the rock below is the Mescal Limestone. Both are Precambrian in age but the Dripping Spring is the older (fig. C4-2); the fault has reversed the order.

The plane of the thrust fault itself is a gouge zone of finely crushed rock about 1 m or 3 ft thick. It is not resistant to weathering, so it forms a recess in the outcrop. Note that banding in the gouge has itself been contorted.

Bedding in both units is approximately parallel to the thrust fault. The Mescal Limestone is locally finely banded and includes limestone, but elsewhere in the outcrop, Mescal contains green and pink calcium-silicate metamorphic minerals (see C8).

Note that we are finally in the roof rocks of the thick Wilderness sill (beginning at about milepost 20.6). There are a few dikes of light-colored granite and pegmatite in this outcrop, however. Some of them are cut by the thrust fault and some are not. Does this mean that the thrust is Eocene, the age of the granite dikes?

C6 -- Deformed metamorphic rocks

This stop is by scenic Inspiration Rock, which is well-marked near milepost 23.5. The metamorphic rock is the dark-colored lustrous rock north of the bold outcrop of light-colored granitic pegmatite. These are among the best outcrops of aluminous metamorphic rocks near the highway; better outcrops are along the Marshall Gulch, Soldier Camp-Butterfly, and Box Camp trails, and the road to Mt. Bigelow.

The metamorphosed rocks here are phyllite and schist formed from shales of the Pioneer Formation (also known as Pioneer Shale) of Precambrian age (fig. C4-2). The lustrous surfaces are along alined micas that have formed by recrystallization of the original clay minerals; these micas are coarse in schist but fine in phyllite. In some specimens, the lustrous foliation surfaces have themselves been kinked or folded into 3-dimensional rather than planar forms. In some schist specimens, quartz and mica have segregated into separate bands. Garnet has crystallized in the schist at some localities but not here.

The recrystallization of these rocks implies high temperatures, and the deformation implies compression during heating. The heat was supplied by nearby igneous intrusions -- but apparently not the nearby light-colored pegmatites (C7) forming Inspiration Rock, which are younger than the deformation and nowhere show baked wallrocks.

C7 -- Pegmatite dikes and Leatherwood granodiorite

Road cuts here show some classic intrusive features. From the junction of the Summerhaven road and the ski-basin road, the latter exposes light-colored pegmatite dikes intruding darker Leatherwood granodiorite (fig. C7-1) all the way to C8.

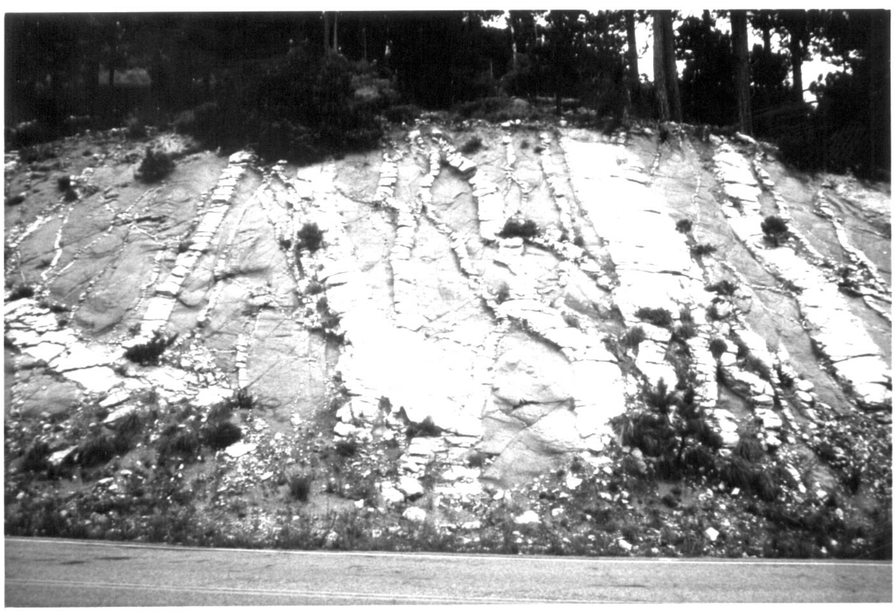


Figure C7-1. Photo of pegmatite dikes in Leatherwood granodiorite

Pegmatite is very coarse-grained granite. Pegmatites are thought to form from the volatile low-density fluids that crystallize last from granitic magma, and our position here in the roof rocks of the Wilderness sill is consistent with that notion.

The pegmatites form steep dikes up to about 3 m (10 ft) thick, in older Leatherwood granodiorite, here quite weathered. The main minerals in these pegmatites are feldspar (chalky white), quartz (blue-gray), both muscovite (clear) and biotite (black) mica, and minor garnet. Quartz may form intergrowths within feldspar called graphic granite, because the intergrowths look like runes or heiroglyphics. Some fine-grained white granite (aplite) also forms dikes.

If you look closely, you'll see that the crystals composing some pegmatite dikes are as large as the dikes are wide, and some grew inward from the dike walls. This shows that crystallization took place right where the crystals are now. The large crystals suggest slow growth in a fluid with low viscosity. When your eyes get used to these rocks, you'll be able to make out the growth patterns of individual crystal aggregates. These include aplite bands draped over large feldspar crystals (fig. C7-2).

Figure C7-2. Photo of growth banding in garnet aplite, showing draped single crystals of pegmatite

The Leatherwood granodiorite, here somewhat weathered, is a dark, salt-and-pepper textured rock. Granodiorite is an igneous rock of the granitic clan, but contains more iron, magnesium, and calcium, and correspondingly less of other constituents, than does true granite. The Leatherwood granodiorite is about 70 million years old, and intruded a large area north of here. It is well exposed for several miles in the upper part of the Control road.

C8 -- Marble and skarn

From about 0.4 mi above the junction (of C7), intermittently past the ski basin to the top of Mt. Lemmon, marble and calcium silicate rock formed by metamorphism of limy sedimentary rock are exposed. Near 0.4 mi are intrusive contacts with Leatherwood granodiorite; the same contact is repeated in several outcrops because of faulting. Figure C8-1 shows the appearance of the best such exposure. Leatherwood granodiorite is gray, whereas metamorphosed sedimentary rocks above it are locally pink and green due to fine-grained garnet and to epidote and other calcium silicate minerals, respectively. Light-colored pegmatites dikes cut both; it is best to mentally extract them when viewing the contact between older rocks.

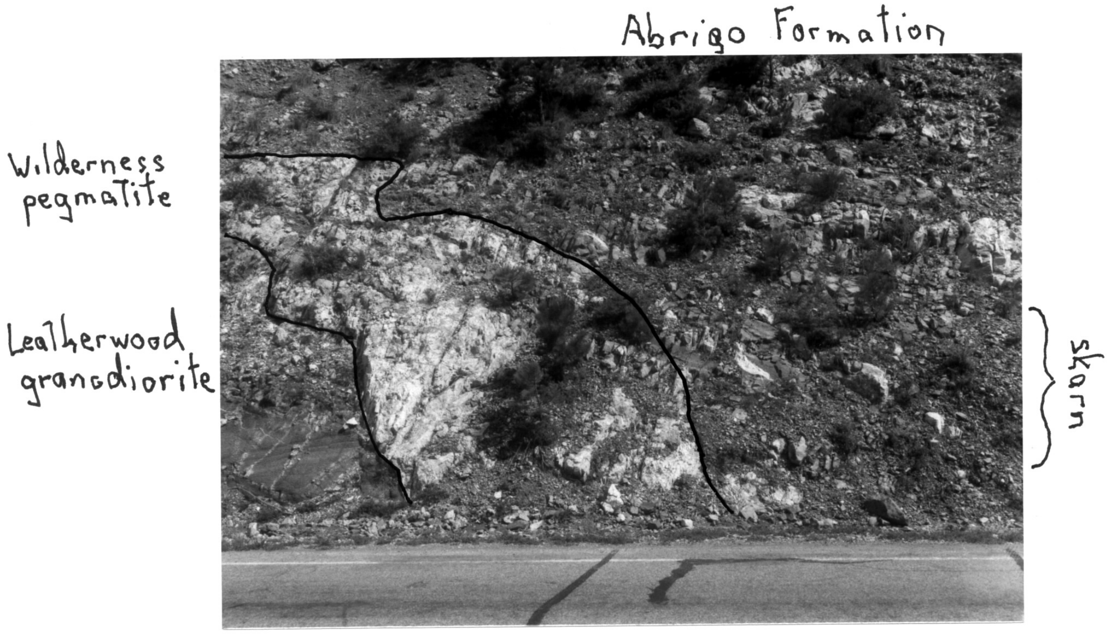


Figure C8-1. Annotated photo of skarn along contact of Leatherwood granodiorite and Abrigo Formation

The intrusive contact of interest here is between Leatherwood granodiorite below and the Abrigo Formation, an impure carbonate sedimentary rock of Cambrian age (fig. C4-2), above. Heavily recrystallized intrusive contacts in limey host rocks are called skarns. Locally these are economic mineral deposits, but that at 0.4 mi is not. Epidote and garnet are the most common skarn minerals here and at many other outcrops in this interval. These are called calc-silicate minerals -- original calcium carbonate and silicate minerals have reacted at high temperatures to form them. Where the Abrigo was originally a fairly pure limestone, marble or coarsely crystalline carbonate rock (usually white to gray) has formed instead of calc-silicate rock.

Skarn and related rocks are so common ahead over such a long interval of road because we are everywhere just a few feet above the Leatherwood intrusive contact; it is exposed in the lower ski basin. The later pegmatite dikes seem unrelated to the skarns. Probably the Leatherwood was at about 700^{o} C (1450^{o} F) or more when it intruded, whereas the pegmatite may have been at about 500^{o} C (1050^{o} F), so the Leatherwood was a far more potent baker.

C9 -- Garnet aplite

The next outcrop is equally good for understanding igneous rocks and for aesthetic beauty. Return to the junction of the ski basin and Summerhaven roads. Continue through Summerhaven toward Marshall Gulch. Past Summerhaven post office about 0.7 mi but before entering the white-walled gorge of Sabino Creek, turn left (east) onto a dirt road. The large white whaleback outcrop ahead on the left is our destination. A band of garnet aplite (fig. C9-1) runs the length of the outcrop.

Figure C9-1. Annotated photo of garnet aplite

This outcrop consists of pegmatite (C7), aplite (fine-grained light-colored granite), and inclusions of dark Leatherwood granodiorite. The most remarkable feature of the outcrop, however, are bands of garnet-bearing aplite that extend the length of the outcrop -- actually they have been traced to the east, then south, for about a kilometer (0.7 mi) toward the south side of Inspiration Rock (C6).

The bands contain so much fine garnet that some are deep red, and they are extremely continuous, reminding some observers of railroad tracks. The few discontinuities are formed by dikes of younger pegmatite that cut the garnet aplite at oblique angles and spread the garnet bands apart, thus causing them to be offset (fig. C9-2). The garnet bands were originally continuous across these gaps.

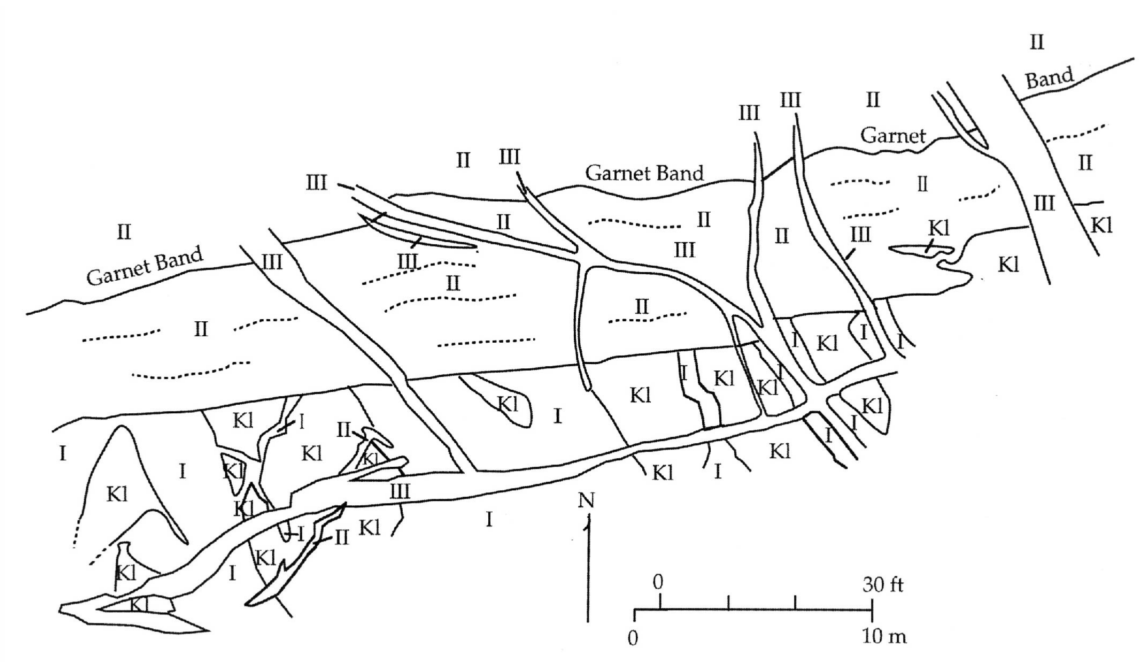


Figure C9-2. Map of pegmatite and garnet aplite; I, II, and III are pegmatites and aplites of decreasing age, Kl is Leatherwood granodiorite

The bands are steeply dipping now and apparently were steeply dipping originally, as older sedimentary rocks nearby (C8) are tilted only a little. The garnet bands must have formed along the walls of a steep fissure filling with aplite. Reconstruction of these walls suggests that they consisted of older pegmatite and Leatherwood granodiorite (fig. C9-2). You may be able to reconstruct still earlier stages when all the wallrocks were Leatherwood granodiorite.

As at C7, minor features of the aplites and pegmatites here reveal some details of their formation. The gorge of Sabino Creek along the paved road below exposes similar rocks.

C10 -- Pegmatite, unconformity, and pot holes

This lovely area shows some quite disparate geologic features. It is near Marshall Gulch parking lot, well marked at the end of the paved road below Summerhaven about 1.3 mi. Continue on foot downstream along the bed of Sabino Creek about 160 m (530 ft) to the first of the plunge pools and pot holes in light-colored pegmatite (fig. C10-1). The beginning of the Sunset Trail is here, bearing around to the left (east) along the slope.

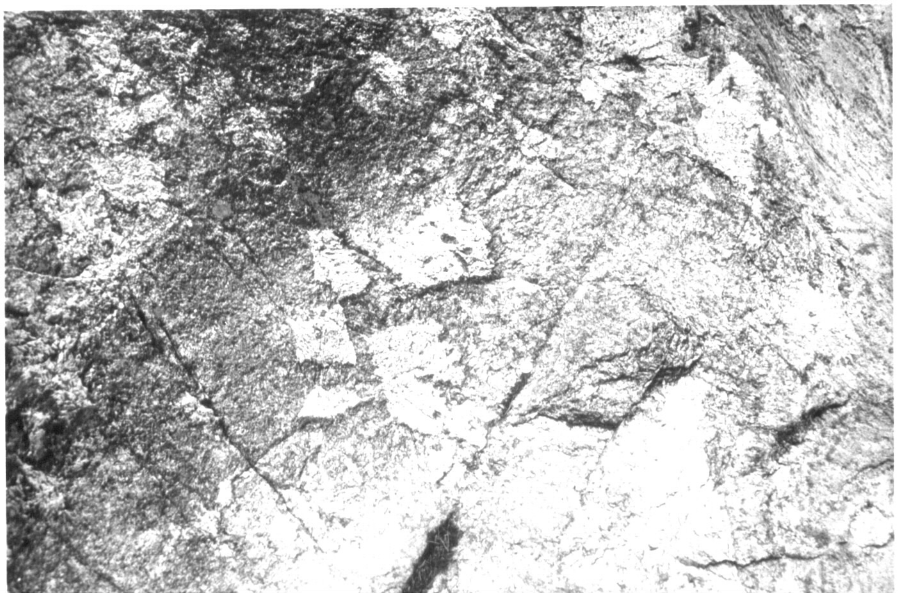


Figure C10-1. Photo of pegmatite texture in plunge pool of Sabino Creek

Pegmatite here shows a texture that is unusual. Large crystals of feldspar containing graphic quartz intergrowths (see C7) are embedded in much finer granite (fig. C10-1). Micas and garnet form a rim around these crystals. The texture suggests a change of conditions from slow crystallization of thin volatile-rich melt, which favors pegmatite formation, to fast crystallization of the remaining melt, which favors fine granite. The rims suggest chemical reactions between older crystals and melt. Also present are large inclusions of Oracle Granite.

The bed of Sabino Creek here shows some pot holes (in addition to plunge pools under waterfalls). These are formed by the grinding of cobbles and boulders swept around by the turbulent motion of the stream. Some of the potholes are still active and growing, but others are visible in cross-section in the banks of the stream. These are remnants of old pot holes subsequently cut through by stream-bed erosion.

Along the beginning of the Sunset Trail past here, you will see displaced boulders of coarse-grained Oracle Granite and Scanlan Conglomerate (fig. C10-2), the lower member of the Pioneer Formation (fig. C4-2), in addition to pegmatite and other rocks. Both the Oracle and the Scanlan are Precambrian, but the Oracle is older. Pegmatite is much younger than either. The Scanlan is a deposit of pebbles formed on an eroded surface of Oracle Granite. Thus we are seeing a fragment of a Precambrian landscape. The buried erosion surface itself is called an unconformity, and is better exposed about a half mile up Sunset Trail.

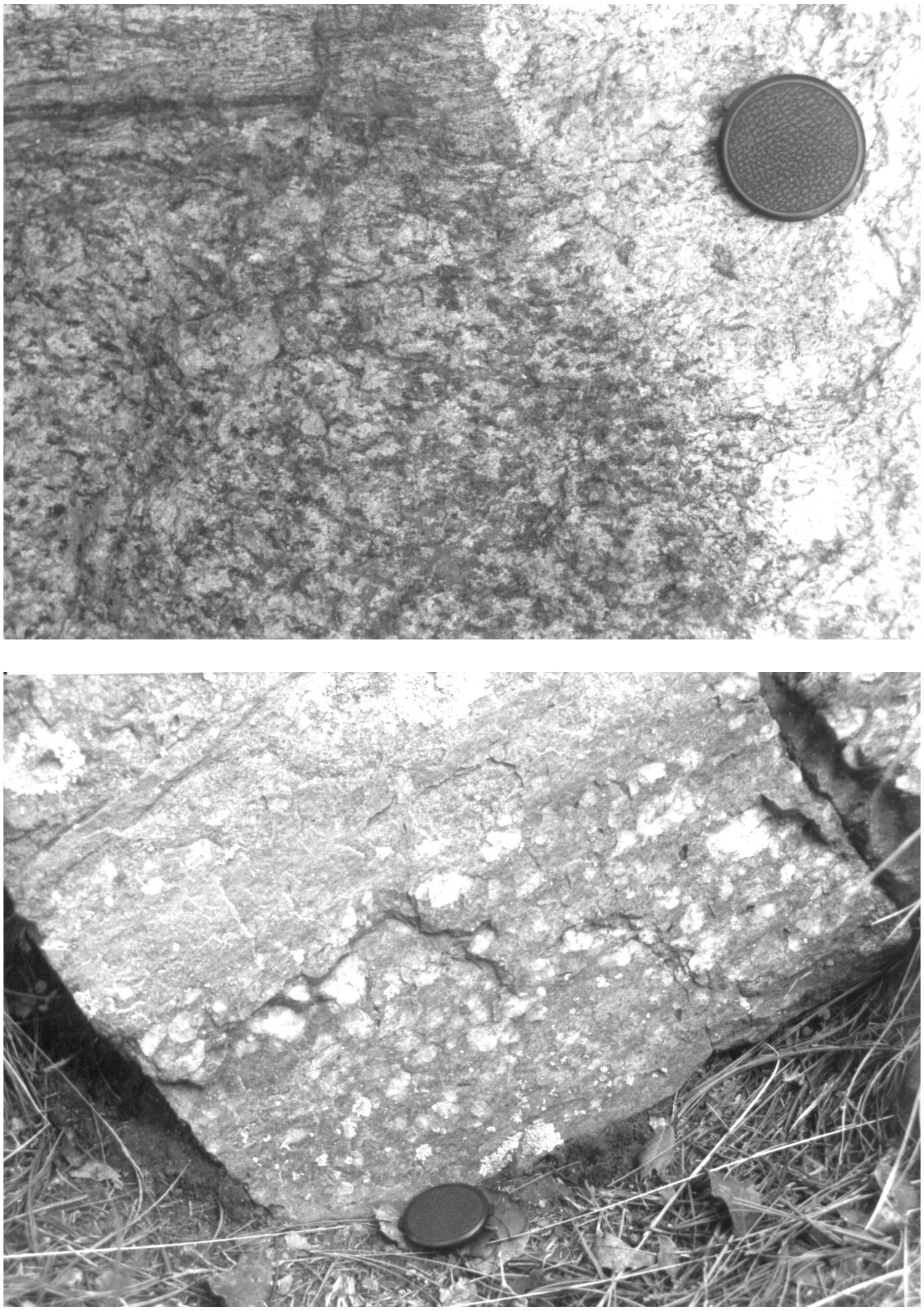


Figure C10-2. Photos of typical Oracle Granite (a) and Scanlan Conglomerate (b) on Sunset Trail

BIBLIOGRAPHY

Force, E. R., 1997, Geology of the the Santa Catalina Mountains, southeastern Arizona: a cross-sectional approach: Monographs in Mineral Resource Science #1, 135 p.

Keith, S. B., Reynolds, S. J., Damon, P. E., Shafiqullah, Muhammad, Livingston, D. E., and Pushkar, P. D., 1980, Evidence for multiple intrusion and deformation within the Santa Catalina-Rincon-Tortolita crystalline complex, southeastern Arizona, *in* Crittenden, M. D., Coney, P. J., and Davis, G. H., eds., Cordilleran metamorphic core complexes: Geological Society of America Memoir 153, p. 217-267.

Reynolds, S. J., and Lister, G. S., 1990, Folding of mylonitic zones in Cordilleran metamorphic core complexes--evidence from near the mylonitic front: Geology, v. 18, p. 216-219.

Eric Force biography

Eric Force of the U. S. Geological Survey in Tucson studied and mapped the geology of the Catalinas from 1989 intermittently to 1995. He is also the titanium-mineral and formerly the manganese resource specialist for USGS, and has worked extensively throughout the United States and abroad.