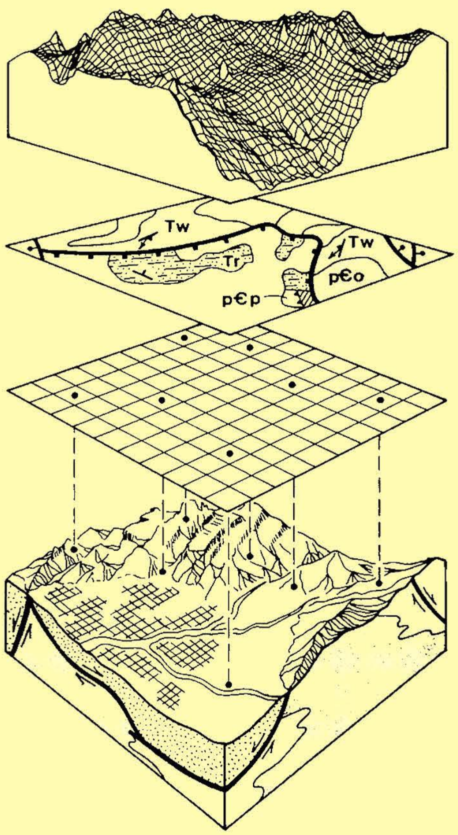
FRONTIERS IN GEOLOGY AND ORE DEPOSITS OF ARIZONA AND THE SOUTHWEST

Arizona Geological Society and the University of Arizona 1986 Symposium



FIELD TRIP GUIDEBOOK
3

Precious Metal Mineralization, Stratigraphy, and Tectonics In Southeastern California

March 17-19 1986

Leaders: W. Wilkinson and C. Wendt (NICOR), J. Wilkins (St. Joe Minerals), G. Haxel (U.S.G.S.)

Coordinator: J. Wilkins

ARIZONA GEOLOGICAL SOCIETY
TUCSON, ARIZONA

Cover preparation by Beverly Morgan, modified from J. Mehulka and P. Mirocha, AGS Digest Volume XVI

ARIZONA GEOLOGICAL SOCIETY
P.O. BOX 40952, UNIVERSITY STATION
TUCSON, ARIZONA 85719

To: Field Trip Participants

Welcome to Arizona and the 1986 Arizona Geological Society Symposium "Frontiers in Geology and Ore Deposits of Arizona and the Southwest." As field trip chairman I would like to wish you an enjoyable and informative conference and a worthwhile field trip experience.

The field trip committee set out many months ago to provide field exposure to a broad spectrum of geological disciplines. The results include trips to recent precious-metal discoveries, areas of new and developing stratigraphic and structure concepts, industrial mineral resources, lithologic features significant to the petroleum potential in the Southwest, geologic hazards in the community, and an opportunity to attend trips from previous Arizona Geological Society meetings. We hope you find your chosen field trip as exciting as we intended.

At this time of very limited support from industry, it is especially important to acknowledge the personal efforts of so many. I include in those the planning and follow through of the field trip committee, the many hours of preparation by the trip leaders, and the commitment of the trip coordinators to a smooth-running trip. A special thanks goes to Maggie Morris of the University of Arizona Conference Department for the transportation, lodging, and meal arrangements.

Please enjoy the Southwest and remember this week of field trips and meetings as a step toward the frontiers of the future.

Best regards,

Parry D. Willard

Parry D. Willard
Field Trip Chairman

Field Trip Committee

Annon Cook
Norm Lehman
Beverly Morgan
Jon Spencer
Erick Weiland
Joe Wilkins Jr.
Jan Wilt

ITINERARY

FIELD TRIP 3

PRECIOUS-METAL MINERALIZATION, STRATIGRAPHY, AND TECTONICS IN SOUTHEASTERN ARIZONA

General Leaders:	William H. Wilkinson and Clancy J. Wendt (Nicor), Gordon B. Haxel (USGS), Joe Wilkins Jr. (St. Joe Minerals)
Coordinator:	Joe Wilkins Jr. (St. Joe Minerals)

Monday, March 17, 1986

4:00 pm	Depart from University of Arizona, front of Student Union. Travel to Yuma, Ariz.
8:00 pm	Arrive and check in at Stardust Resort Motor Inn,* Yuma, Ariz. (602-783-8861)

Tuesday, March 18, 1986

7:00 am	Depart from Stardust Motel
8:15 am	Stop 1. Gavilan Hills—a walking tour (4 hours)
12:15 pm	Return to vehicles. Lunch*
2:00 pm	Stop 2. Overview of Mesquite mine
3:15 pm	Stop 3. Cargo Muchacho Mountains—visits to American Girl, American Boy, and Padre-Madre mines
5:15 pm	Return to Yuma
7:00 pm	Steak fry* at Stardust Resort

Wednesday, March 19, 1986

7:00 am	Check out and depart from Stardust Motel
7:30 am	Stop 1. Overview of Picacho Basin
8:00 am	Stop 2. Traverse to examine structural behavior of rocks along the detachment fault
9:15 am	Stop 3. Traverse through Winterhaven Formation onto the detachment fault
10:30 pm	Stop 4. Exposure of cataclastic ledge
11:15 pm	Stops 5 and 6. Picacho mine. Lunch* between stops
1:30 pm	Depart for Tucson
6:00 pm	Arrive in Tucson. Stops at Holiday Inn (Broadway) and University of Arizona

*Included in fees.

Drivers:	David Young	Gail Liebler
	Mark Bradley	Bob Smith

Field boots required. If possible, bring hard hat and safety glasses for mine tours.

FIELD TRIP 3

PRECIOUS-METAL MINERALIZATION, STRATIGRAPHY, AND TECTONICS IN SOUTHEASTERN ARIZONA

March 17-19, 1986

General Leaders: William H. Wilkinson (Nicor)
Clancy J. Wendt (Nicor)
Gordon B. Haxel (U.S. Geological Survey)
Joe Wilkins Jr. (St. Joe Minerals)

Associate Leaders: Peter A Drobeck (Consultant)
Gail S. Liebler (University of Arizona)
Eric G. Frost (University of California, Santa Barbara)

Coordinator: Joe Wilkins Jr (St. Joe Minerals)

DAY 1

Arizona Geological Society Digest Volume XVI, 1986

PRECIOUS METAL MINERALIZATION, STRATIGRAPHY, AND TECTONICS IN SOUTHEASTERN CALIFORNIA

William H. Wilkinson and Clancy J. Wendt

NICOR Mineral Ventures
2341 S. Friebus, Suite 12
Tucson, AZ 85713

Recent successes by exploration geologists from several companies have led to announcements of gold discoveries and created a gold rush in southeastern California. Two of these discoveries, Picacho and Mesquite, are now in production. The influx of geologists from industry, the U.S. Geological Survey, and academia has spurred the evolution of geologic thought in the region. The willingness of industry to share some of its data has made a significant contribution to this evolutionary process. It is the opportunity to draw upon this data base of knowledge that has made this field trip possible.

The purpose of this trip is to examine several precious metal deposits in southeastern California. The relationships of these deposits to their regional stratigraphic position and to the late Cretaceous to middle Tertiary structural-tectonic setting will be examined.

The field trip will be subdivided into several subtrips which will be led by individuals who have conducted extensive field work in the region:

1) Dr. Gordon Haxel (U.S. Geological Survey) will lead the trip through the Gavilan Hills where we will look in detail at the Chocolate Mountains thrust; structural, stratigraphic, and mineralogical aspects of the Orocopia Schist; and a brief look at the rocks that form the upper plate of the Chocolate Mountains thrust.
2) A brief overview stop along the highway will be made at Gold Fields Mining Corporation's Mesquite mine where Wendt and Wilkinson will lead an informal discussion.
3) A geologist from Newmont will conduct a tour of their properties in the Cargo Muchacho Mountains. Stops will be made at the American Girl and Padre-Madre mines where stratigraphy, structure, and mineralization will be discussed.
4) Peter A. Drobeck (Western States Minerals) and Gail S. Liebler (graduate student, University of Arizona) will guide us through the Picacho mine and surrounding areas. The emphasis here will be on the nature and geometry of detachment faulting and the structural control of Au mineralization in the Picacho mine.

The field trip is divided into two days, each originating in Yuma, Arizona. Detailed road logs and general stop discussions for each day are presented below. Figure 1 shows the routes and principal stops for each day.

FIRST DAY ROAD LOG

TUESDAY, MARCH 18, 1986

YUMA - GAVILAN HILLS - MESQUITE MINE - CARGO MUCHACHO MOUNTAINS

Assembly Point: Stardust Motel
Distance: 120 miles
Stops: 4

Mileage	
0.0	Parking lot of Stardust Motel. Turn left and proceed north on 4th Avenue. 0.9
0.9	Junction of U.S. 95, continue north on 4th Avenue. 1.6
2.5	Intersection of Giss Parkway, continue north. Sign points directions to Yuma Territorial Prison State Park. Between 1876 and 1909, this penetentiary housed many of Arizona's most dangerous criminals. Famed in literature, movies and television, the remains of the prison are now an Arizona State Park. The cells, main gate and guard tower have endured as grim reminders of frontier justice. Museum exhibits document the story of the prison. 0.5
3.0	Cross Colorado River, enter California. 0.2
3.2	Turn left onto ramp to I-8 W. 1.2

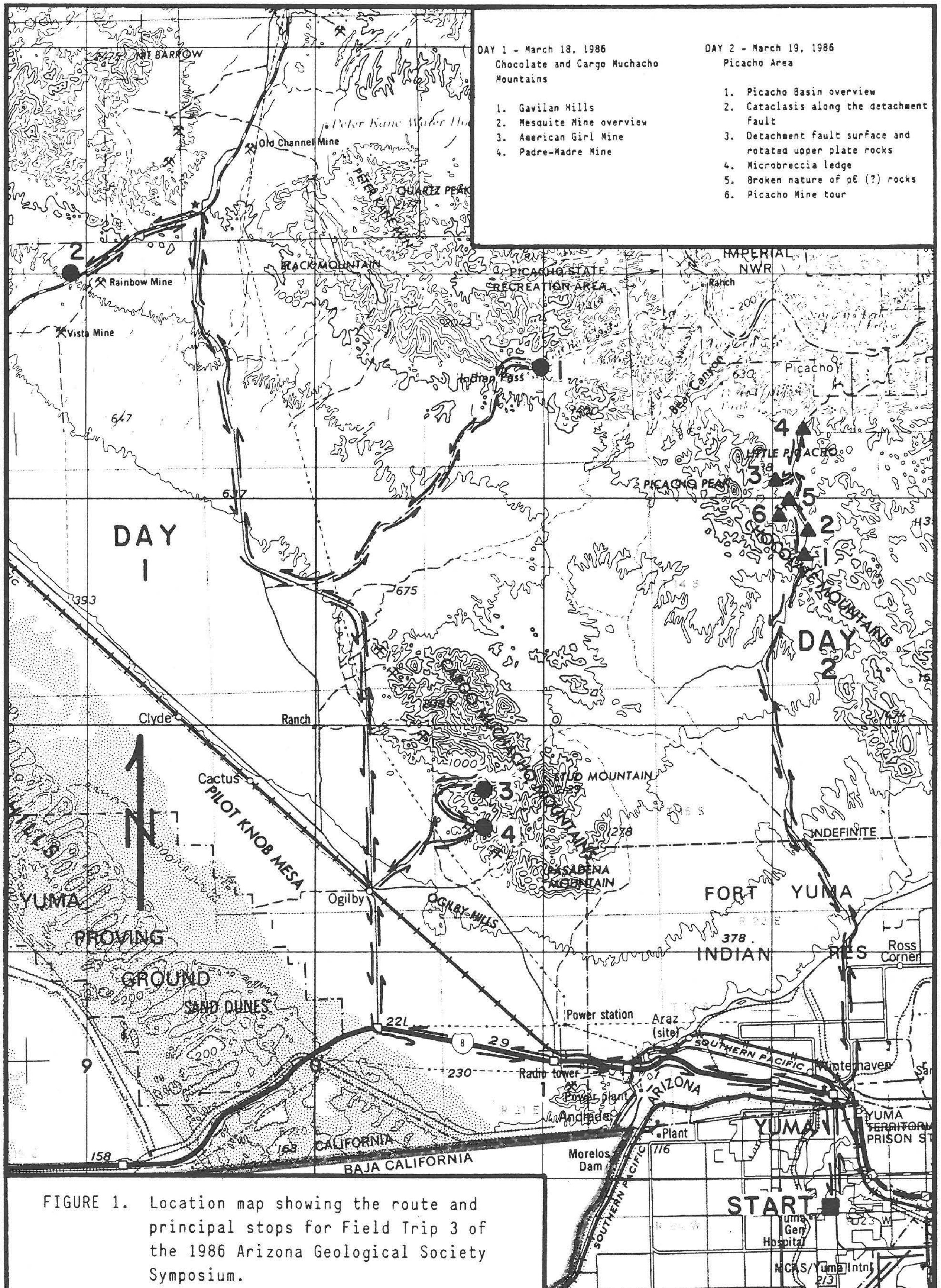


FIGURE 1. Location map showing the route and principal stops for Field Trip 3 of the 1986 Arizona Geological Society Symposium.

4.4 Driving along Colorado River floodplain. This area suffered extensive flooding in 1983. Cargo Muchacho Mountains at 2:00. 3.0

7.4 Small adobe building at 2:00 marks old stage coach station. Begin ascent from floodplain. 0.4

7.8 Old tailings piles at right mark site of mill which purportedly processed gold ore from the Padre-Madre mine in the Cargo Muchacho Mountains. 0.8

8.6 Cross All American Canal. 0.1

8.7 Exit for Algodones, Mexico. 1.4

10.1 California Border Inspection Station. All vehicles must stop. Pilot Knob at 9:00. Pilot Knob is made up of hornblende-biotite granodiorite to quartz monzonite augen gneiss which is intrusive into metamorphic rocks similar to the Tumco Formation and into a mafic igneous complex dated at approximately 1.7 b.y. (Dillon, 1975). The hornblende-biotite granodiorite to quartz monzonite augen gneiss of Pilot Knob is being quarryed at the Andrade Quarry for construction material. 1.1

11.2 Ascend onto pediment surface. Cargo Muchacho Mountains at 3:00. Sand Hills visible from 9:00-1:00. The Sand Hills, also known as the "American Sahara", are an exciting formation of sand dunes which have been used as a movie site for half a century. They offer a year round location for desert vehicle sports, photography, and vacation fun. The Sand Hills mark the southeastern projection of the San Andreas Fault.

GEOLOGY OF THE CARGO MUCHACHO MOUNTAINS

The rocks exposed in the Cargo Muchacho Mountains occupy the upper plate of the Chocolate Mountains thrust (CMT). The CMT is not exposed in the range nor are any mid-Tertiary igneous rocks.

The oldest rocks comprise a mafic to intermediate meta-igneous complex. These rocks are now orthogneisses composed of metamorphosed hornblende quartz diorite to diorite with lesser amounts of metagabbro and amphibolite.

Banded and laminated orthogneisses and paragneisses have equivocal contact relationships with the meta-igneous complex. The Tumco Formation of the Cargo Muchacho Mountains is included in the banded gneisses. Henshaw (1942) named the Tumco Formation for a sequence of arkosites and hornblende schists.

Dillon's (1975) descriptions indicate that light gray, medium-grained, quartzofeldspathic, laminated gneisses constitute over 95 percent of the Tumco Formation. Minor interlayers of quartzite, marble, and amphibolite and a few amphibolite dikes are present. These rocks probably had a sedimentary and/or volcanic origin.

The relative ages of the mafic meta-igneous complex and the banded gneisses are unknown. On Pilot Knob rocks similar to the meta-igneous complex are intruded by a hornblende-biotite granodiorite to quartz monzonite augen gneiss which yielded a U/Pb apparent age on zircons of 1.7 b.y. (Dillon, 1975, p.21). The banded gneisses are also considered to be Precambrian(?) based on similarities to dated rocks in Arizona and on intrusive relationships with undated rocks similar to the granodiorite gneiss at Pilot Knob.

Prior to thrusting, the pre-Phanerozoic rocks were intruded by at least five types of granitic magmas during the Mesozoic; three are present in the Cargo Muchachos. The oldest is a hornblende-biotite quartz monzonite pluton which covers at least 16 square miles in the southeastern part of the range. This unit has been dated at 173 ± 1 m.y. by the U/Pb method on zircons (Dillon, 1975, p.77). Dillon mapped three facies to this pluton: a slightly blastoporphyritic facies, a coarsely blastoporphyritic facies, and migmatites.

The quartz monzonite is intruded by a biotite granite and associated aplites and pegmatites. A U/Pb age of 145 ± 1 m.y. was obtained from a single zircon separate from this rock (Dillon, 1975, p.90). This Jurassic biotite granite cuts older foliation in the mafic meta-igneous complex, the Tumco Formation, and the hornblende quartz monzonite of Pilot Knob but is itself strongly foliated. Five K-Ar ages from the pluton and its wall rocks range from 53 to 58 m.y. (Armstrong and Suppe, 1973). These dates are interpreted to be reset ages reflecting cooling ages of a later thermal event. The biotite granite and its associated rocks cover about 15 square miles of the northern Cargo Muchachos.

The Vitrefax Formation was named by Henshaw (1942) for unusual kyanite-quartz rocks and associated muscovite-aluminosilicate and biotite-aluminosilicate schists found near the mouth of American Girl Canyon. Accessory minerals include tourmaline, rutile, ilmenite, magnetite, apatite, pyrophyllite, calcite, sphene, lazulite, pyrite, and dumortierite. The Vitrefax Formation is exposed along the west and southwest margin of the Jurassic biotite granite. Dillon (1975) and Tosdal et al. (1985) interpret the formation of the Vitrefax by leaching of the Tumco Formation by supercritical fluids escaping under high pressure from the rapidly crystallizing granite. An alternative explanation is that the extremely aluminosilicate-rich rocks are the result of metamorphosed argillic to advanced argillic alteration phases.

Aplitic and pegmatitic muscovite-garnet-biotite gneisses occur as dikes, sills, and irregular masses cutting foliation in the Jurassic biotite granite. Muscovite, which defines a foliation in these gneisses, was dated at 49 and 53 m.y. (K-Ar, Dillon, 1975, p.107). These rocks form spectacular dike swarms on the west side of the range and represent differentiated products of the peraluminous-calcic magma series. They are higher level, more differentiated, and more oxidized suites than the aplites and pegmatites in the Chocolate Mountains (Stan Keith, pers. comm.).

As noted earlier, the regional CMT is not exposed in the Cargo Muchacho Mountains. However, there are a number of low angle structures which have been variously interpreted as stacked thrust faults or stacked detachment faults, some of which may have reactivated earlier thrust faults. Gold mineralization is associated with some of these low angle structures.

The low angle structures are cut by northwest-trending, steeply dipping faults with right-lateral separation of up to one half mile. These faults are parallel to the San Andreas Fault. East-west trending faults with both vertical and left-lateral separation postdate mid-Tertiary volcanism and offset Pliocene and Pleistocene Colorado River deposits.

Two mining districts, Cargo Muchacho and Tumco, are located in the Cargo Muchacho Mountains. Mining was first done in this region by Spaniards as early as 1780-81, the earliest mining recorded in California. Later mining resumed under Mexican rule where the mountains and district got their name, Cargo Muchacho -- Loaded Boy. Total historic production from the two districts in gold and silver has been about $4.8 million (Morton, 1977). 5.4

15.5 Turn right (north) at Ogilby Road/Blythe exit and proceed north on Ogilby Road. Chocolate Mountains from 10:00 - 11:30, Cargo Muchacho Mountains from 12:00 - 2:00. 3.9

19.4 Railroad crossing at old townsite of Ogilby. 0.2

19.6 American Girl Mine Road to right, continue north. 2.4

22.0 American Girl Canyon at 3:00. 0.6

22.6 Pegmatite dike swarm cutting Tumco Formation at 12:00 - 3:00. 1.3

23.9 Gold Rock Ranch road to left, Tumco to right. Proceed north. Gold Rock Ranch was a temporary headquarters for General Patton for tank training maneuvers during World War II. Remnants of troop activities can still be seen there.

TUMCO

The Tumco district has produced about $2,863,000 in gold. The deposit was discovered in 1884 by Peter Walters and named the Gold Rock Mine. In 1893, California investors incorporated the Golden Cross Mining and Milling Company to work the richest claims. Around the company's forty-stamp mill rose the unsavory company town of Hedges, described as being " a rough place, down in a hollow ... where there were plenty of gunfights, knifings, and killings in the saloons and gambling places" (Paher, 1976). In 1910 the operations were taken over by the United Mines Company and renamed Tumco. Seeley W. Mudd operated the mines from 1913-14. Developments include a 1200-foot inclined shaft at the Golden Crown and 1100-foot shafts at the Golden Cross and Golden Queen workings.

The mineralized zones lie parallel to bedding planes in the Tumco Formation which is intruded by numerous narrow pegmatite dikes which are highly irregular in form and orientation. The bedding planes and foliation strike N 40-80° E and dip 25-50° SE. The thickness of the gold-bearing zones ranges from 1 to 70 feet and averages in the range of 5 to 15 feet. Ore shoots are lenticular to tabular in shape. Commonly, the footwall is a regular plane and the hanging wall is irregular. The ore zones are composed dominantly of the country rock in which the feldspars are kaolinized. The gold is very fine-grained and free and sulfides are uncommon, although chalcopyrite and pyrite are present in small amounts. These sulfides are oxidized near the surface (Morton, 1977). 2.2

26.1 Crossing outcrops of Tumco Formation. Black Mountain at 1:00 with radio towers is capped by the Black Mountain basalt. This was the site of one of Patton's communication stations. The road to the top was built by Patton. 0.4

26.5 Hyduke mine road to right. Continue north. The Hyduke mine road leads to several mineralized areas and ultimately winds up near the Picacho mine.

Gold can be panned from all of the washes we are crossing from here to the intersection with State Highway 78. 2.2

28.7 Indian Pass Road - turn right. Picacho Peak at 12:00. 0.5

29.2 Note red-topped Gold Fields' claim posts. Gold Fields is the major claim holder in the area. 0.3

29.5 Crossing under power line. 2.0

31.5 Dumortierite and petrified palm wood can be collected on the low pediment surface to the left. 2.3

33.8 Gavilan Hills on skyline from 12:00 - 2:00.

GEOLOGY OF THE GAVILAN HILLS

Black Mountain forms the ridge line to the left, and the Gavilan Hills are the low hills from 12:00 - 2:00. Black Mountain is capped by the basalt of Black Mountain which consists of blocky, sparsely to moderately vesicular or amygdaloidal, black olivine basalt flows. Plagioclase from the basalt yielded a K-Ar age of 13.3 $\pm$ 3 m.y. (Crowe, 1978). The basalt overlies Miocene-Pliocene conglomerates which form a heterogeneous unit of conglomerate, fanglomerate, sandstone, and breccia.

The Gavilan Hills are the southeastern portion of an anticlinorium that extends northwest through the Chocolate Mountains into the Orocopia Mountains. The Orocopia Schist forms the core of the antiform. The Chocolate Mountains thrust (CMT) is well exposed only on the northeast side of the Gavilan Hills; it is covered by younger rocks on the southwest side. Banded gneisses, similar to those in the Cargo Muchacho Mountains, comprise the upper plate rocks. The Gatuna fault parallels the CMT and displaces banded gneiss against rocks of the Winterhaven Formation along Gavilan Wash. The Gatuna fault has a moderate to low dip to the east and has been interpreted as a detachment fault.

The banded gneisses, which tectonically overlie the Orocopia Schist, are similar to those described in the Cargo Muchacho Mountains and will not be discussed again. The following description of the Orocopia Schist is taken from Haxel and Dillon (1978). The most abundant rock type is a monotonous but distinctive light- to dark-gray, flaggy quartzofeldspathic schist, with a little interlayered mica schist, characterized by ubiquitous flysch-like compositional layering derived from sedimentary bedding. This gray schist is predominantly metagraywacke, probably in part volcaniclastic, with a little metapelite and meta-arkose. Subordinate to minor rock types are, in order of decreasing overall abundance: metabasite as greenschist, albite amphibolite, amphibolite, or, very locally, garnet amphibolite; ferromanganiferous metachert; siliceous marble; and meta-ultramafic rock as antigorite serpentinite, very coarse grained actinolite rock, talc-actinolite schist, or, locally, talc-rock. Two distinctive "index minerals" are present: porphyroblasts of gray to black albite, the color of which is due to included graphite, and aggregates of bright green fuchsite (chrome muscovite). The Orocopia Schist has been correlated with the Pelona Schist of the Transverse Ranges and with the Rand Schist in the Rand Mountains. Evidence for the correlation is summarized in Haxel and Dillon (1978).

The protolith of the Orocopia Schist was a continentally-derived graywacke and shale sequence with subordinate interlayers of basalt, chert, limestone, local pods of ultramafic rocks, and rare diorite dikes (Tosdal et al., 1984). Concordant U/Pb zircon ages of 163.2 and 160.9 m.y. on two fractions from a pre-metamorphic diorite dike intruding the Orocopia Schist provide a Late Jurassic minimum age for the protolith (Mukasa et al., 1984). Conflicting data are presented by Bennet and DePaolo (1982); using Nd isotopes they determined a possible 850 m.y. age for the Pelona Schist.

The Winterhaven Formation is a sequence of clastic sedimentary rocks with a basal volcanic unit and is characterized by dull purple colors. The Winterhaven is Jurassic(?) in age (Haxel et al., 1985) and rests unconformably upon the Orocopia Schist and the banded gneisses. The basal volcanic unit is composed of massive, strongly altered, aphanitic to porphyritic andesite and/or dacite. The volcanic unit is overlain by a quartz arenite unit which is in turn overlain by an argillitic siltstone unit which also contains calcareous graywacke, sandy limestone, and granule to pebble conglomerates with graywacke matrix. Most of the Winterhaven Formation is incipiently to strongly recrystallized and is moderately to steeply dipping to locally overturned, but is otherwise undeformed (Haxel, 1977).

The banded gneiss, Orocopia Schist, and Winterhaven Formation are all intruded by the Cretaceous Marcus Wash Granite. The Marcus Wash Granite is depositionally overlain by mid- to late-Tertiary sedimentary and volcanic rocks. Three phases of the Marcus Wash were mapped by Haxel (1977): rhyolitic aplitic porphyry, foliated metaporphyry, and granite with associated pegmatites and aplites.

The Chocolate Mountains thrust itself is a single, low-dipping surface along which two distinct bodies of rock have been tectonically juxtaposed. The essential character of the thrust is invariable--gneissic rocks everywhere lie atop Orocopia Schist and the gneiss-over-schist geometry is never repeated. Straddling the thrust is the thrust zone--a zone, on the order of 10 to 100 meters thick, of rocks of both the upper plate and lower plate that are texturally distinct, in the field, from rocks further from the thrust. Although the nature of the thrust zone is somewhat variable from place to place, the rocks straddling the thrust form a generalized "tectonic sequence": upper banded gneisses, mylonitic gneisses, thrust fault, mylonitized schist, and Orocopia Schist (Fig. 2).

The synmetamorphic foliation and lineation of the schist are parallel, both locally and areally, to the

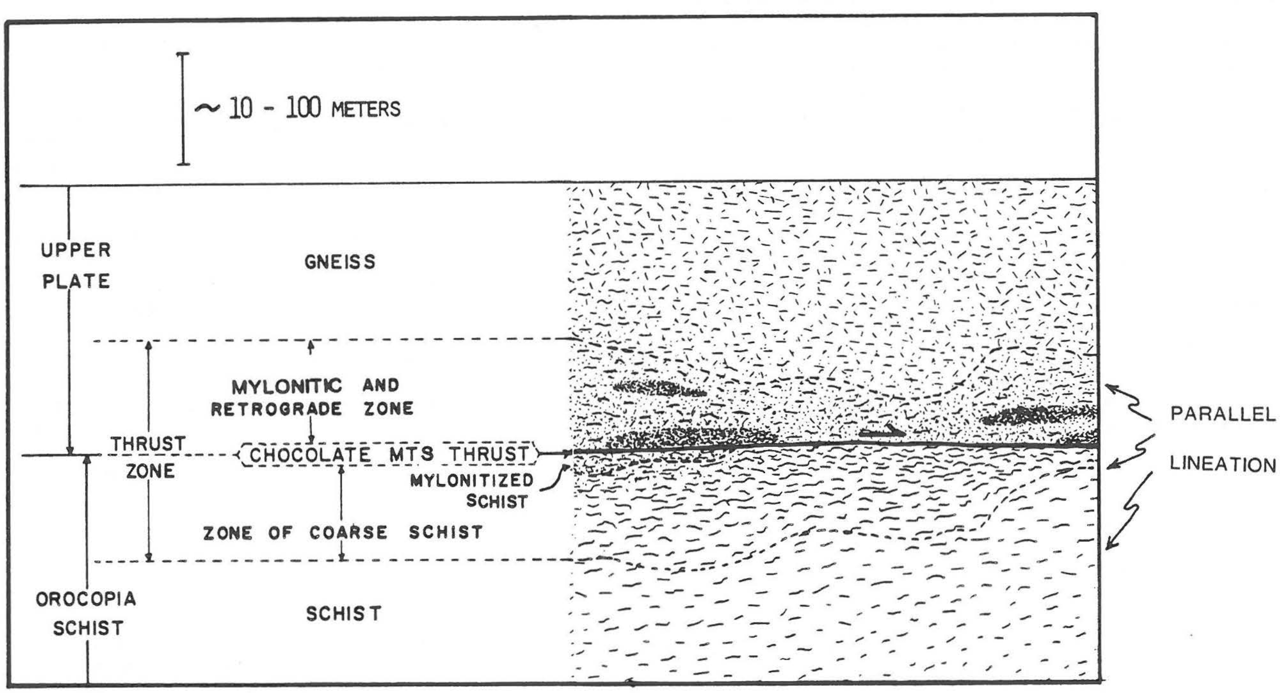


FIGURE 2. Generalized cross section of the Chocolate Mountains thrust zone. Stippling designates mylonitic rocks; dashed contacts are gradational. Figure is from Haxel and Dillon (1978).

foliation and lineation in the cataclastic and retrograde rocks at the base of the upper plate of the thrust. Metamorphic grain size and metamorphic grade within the schist both increase upward toward the overlying thrust. Along many segments of the thrust the cataclastic rocks at the base of the upper plate have been retrograded to the same metamorphic grade as the immediately underlying schist, so that there is a steep metamorphic gradient within the thrust zone but the thrust itself is not a metamorphic discontinuity. These relationships indicate that metamorphism took place beneath the upper plate of the CMT and was generally coeval with the thrust (Haxel and Dillon, 1978). The age of metamorphism of the Orocopia Schist can be constrained by the following: 1.) metamorphism is younger than the 163 m.y. age on pre-metamorphic dikes intruding the Orocopia Schist (Mukasa et al., 1984); 2.) metamorphism is older than the pre-60 m.y. Sortan fault which juxtaposes Orocopia Schist and the Winterhaven Formation (Haxel et al., 1985); and 3.) metamorphism is older than the intrusion of the Cretaceous Marcus Wash Granite. The probable age of metamorphism is late Cretaceous but a late Jurassic age cannot be precluded (Haxel et al., 1985).

Based on structural analyses, Haxel and Dillon (1978) inferred a northeast direction for overthrusting along the CMT. Based on this and radiometric age constraints, Tosdal et al. (1984) proposed that the Orocopia Schist protolith accumulated in an intra-arc rift basin within the western part of the Jurassic magmatic arc. This tectonic setting accounts for both the oceanic depositional environment and the continental provenance of the clastic rocks.

An alternative proposal was presented by Burchfiel and Davis (1981) in which they advocate a westward overthrusting of the Orocopia Schist and correlate the Orocopia Schist with Franciscan rocks. Their interpretation is based largely on their perceived lack of data supporting Haxel and Dillon's model. The age dates of 163.2 and 160.9 m.y. (Mukasa et al., 1984) indicate the protolith of the Orocopia Schist is older than the Franciscan Formation. These age constraints argue strongly against Burchfiel and Davis' ideas. Detailed structural analysis of the Pelona Schist by Jacobson (1983a, 1983b) failed to produce definitive kinematic indicators.

Weak mineralization occurs along the CMT in Gavilan Wash. Several holes have been drilled by Gold Fields as noted in the roadlog. A wilderness study report on the Indian Pass W.S.A. (Rumsey and McMahan, 1984) indicates low grade gold-silver resources may exist along the thrust. Anomalous mineralization occurs along the CMT and in rocks immediately above and below. The highest gold value, 0.26 oz/ton, occurred in a quartz lens immediately below the thrust. Copper is locally anomalous and arsenic values may range from 250 to 1,500 ppm along the thrust. 0.4

34.2 On right side of road note the low white posts marking Gold Fields' drill holes. They drilled a fence of holes from here to 35.0. The young gravels form a thin cover in this area, so depths to bedrock are shallow. Outcrops are locally exposed in the washes. 0.2

34.4 Road to right leads to Indian Pass prospect of Dick and Ann Singer. A muscovite-biotite-garnet-tourmaline granite outcrops here near iron-stained gneisses which carry weakly anomalous gold values. Numerous small pits have been dug in the area. 2.1

36.5 Approximate location of Indian Pass placer workings. 0.8

37.3 Indian Pass, begin descent into Gavilan Wash. Black Mountain on left, Gavilan Hills on right. Miocene to Oligocene volcanic rocks form the craggy peaks on the skyline. The gray-green rocks forming the low hills this side of the volcanic rocks are part of the sedimentary rocks of the Winterhaven Formation. Outcrops on the left are Tertiary conglomerates below the Black Mountain basalt. 0.3

37.6 Contact between the Tertiary conglomerates and the Orocopia Schist. 0.15

37.75 Crossing the approximate trace of the Chocolate Mountains thrust. 0.05

37.8 Enter Gavilan Wash, turn right and proceed down the wash. Gold Fields has drilled a number of holes up the wash to the left. Rocks on both sides of the wash are banded gneiss in the upper plate of the CMT. 0.5

38.3 Another Gold Fields drill hole, additional drilling on terrace to left. Dark green and purple rocks on left are sedimentary rocks of the Winterhaven Formation. 0.3

38.6 Winterhaven sedimentary rocks, note dips of 35 to 70°. These dips have been interpreted to reflect rotation of these rocks against a detachment fault (Gatuna fault) exposed to the right between Gavilan Wash and the Chocolate Mountains thrust. 0.05

38.65 Outcrop of banded gneiss. 0.05

38.7 Winterhaven sedimentary rocks outcrop on left again. 0.3

39.0 Stop 1. Park vehicles at left. On the right side of the wash, a steep vehicle trail ascends the terrace. Walk onto the terrace to begin a 2-mile traverse.

This stop will be a walking traverse led by Gordon B. Haxel, U. S. Geological Survey. Stops will concentrate on the lithology, mineralogy, and structural fabrics of the Orocopia Schist and the Chocolate Mountains thrust. All of the lithologies contained in the Orocopia Schist can be seen on this traverse. Stops will also be made to examine the upper plate gneisses, the Winterhaven Formation, and the Gatuna fault. (See detailed log of this traverse by Haxel, Tosdal, and Dillon immediately following this log.)

Return to vehicles and retrace route through Indian Pass to Ogilby Road. 10.3

49.3 Turn right onto Ogilby Road and proceed to the north. Note the numerous tracks crisscrossing the desert pavement from here to the intersection. These tracks are remnants from tank training maneuvers supervised by General George S. Patton during World War II. Rock cairns, used as fortifications for infantry troops, can still be found against the foothills of Black Mountain. 3.3

52.6 Road to right leads to Laguna placers and exposures of the Orocopia Schist and the Chocolate Mountains thrust. Gold Fields drilled another fence of holes approximately 2 miles up this road. These two fences of holes were drilled along the projected trace of the Chocolate Mountains thrust as mapped near Mesquite by Dillon (1975).

Good view of Chocolate Mountains to northwest.

GEOLOGY OF THE CHOCOLATE MOUNTAINS

The geologic setting of the Chocolate Mountains is similar to that of the Cargo Muchacho Mountains. The main difference is the presence of excellent exposures of the Orocopia Schist and the Chocolate Mountains thrust (CMT) in the Chocolate Mountains. The mafic meta-igneous complex is present with some additional lithologies. Anorthositic gabbro and meta-ultramafic rocks are mapped in the southern Chocolate Mountains. These rocks are possibly correlative with anorthosites in the Transverse Ranges (Dillon, 1975). The Tumco Formation is not mapped in the Chocolate Mountains but a possible correlative unit is recognized and mapped as banded gneiss. Three different lithologies are recognized: banded orthogneiss, banded gneiss of unknown origin, and banded paragneiss. Quartzo-feldspathic gneisses and schists are the most abundant lithology with lesser amounts of amphibolite, quartzite, calc-silicate rocks, marble, and metapelite. Although these rocks may be correlative with the Tumco Formation, they do contain greater amounts of amphibolite and thinner quartzite and marble units than the Tumco Formation.

All five of the pre-thrust Mesozoic intrusive rocks are recognized in the Chocolate Mountains. A Triassic garnet granodiorite to diorite occurs along the southern flank of the range. This rock yielded a concordant U/Pb apparent age of 235 m.y. from zircons (Dillon, 1975, p. 74) and is tentatively correlated with the similar (lithology and age) Lowe Granodiorite in the San Gabriel Mountains. A hornblende-biotite quartz monzonite intrusive is similar mineralogically to the quartz monzonite pluton in the Cargo Muchacho Mountains (dated at 173 $\pm$ 1 m.y.). It underlies at least six square miles along the southern flank of the range.

Biotite granodiorite, including quartz monzonite and quartz diorite, is the most common of the Mesozoic upper plate orthogneisses in the Chocolate Mountains. It may have been emplaced synchronously with the Jurassic granite in the Cargo Muchacho Mountains because: 1) they are petrographically alike; 2) both are probably younger than the hornblende-biotite quartz monzonite; and 3) both have associated pegmatite and aplite phases (Dillon, 1975).

Aplitic and pegmatitic, muscovite-biotite-garnet gneisses (49 to 53 m.y.) are widespread in the southern Chocolate Mountains where they often carry disseminated sulfides. According to Stan Keith (pers. comm.), these rocks are more biotite-rich and garnet-poor than their equivalents in the Cargo Muchacho Mountains. Although thses dikes are members of the peraluminous-calcic magma series, he feels they are less differentiated, less oxidized, and formed closer to the source than those in the Cargo Muchacho Mountains.

Chloritized hornblende-biotite quartz diorite orthogneisses form dikes, sills, and small masses along the southwest flank of the range and are the youngest gneisses in the upper plate of the CMT. These gneisses cut the aplitic and pegmatitic gneisses.

The Orocopia Schist forms the lower plate to the CMT and the core of the Chocolate Mountains anticlinorium. The schist is similar to that described in the Gavilan Hills.

Minor phyllitic rocks and cross-cutting granitic intrusions in some washes are correlated with the Winterhaven Formation and the Marcus Wash Granite, respectively.

Calc-alkaline plutonic and volcanic rocks of the southern Chocolate Mountains intrude and unconformably overlie both plates of the Chocolate Mountains thrust and postdate latest Mesozoic and/or earliest Tertiary movement and metamorphism associated with the thrusting. These silicic magmatic rocks are unconformably overlain by fanglomerate interbedded with basalt that has been radiometrically dated at 13 $\pm$ 2 m.y. (Dillon, 1975). The silicic volcanic rocks are correlated on stratigraphic, petrographic, and chemical grounds with 31 to 25 m.y. old volcanic rocks exposed nearby in the Picacho and Peter Kane Mountain areas. These include the Quechan volcanics and related rocks, ignimbrites, silicic lava flows, and pyroxene trachyandesite lava flows. Intrusive and stratigraphic relationships along with K-Ar ages show that the intrusive rocks (quartz monzonite of Mount Barrow) in the southern Chocolate Mountains are approximately the same age as the volcanic rocks (20.0 $\pm$ 0.6 to 23.4 $\pm$ 0.7 m.y., hornblende and biotite, Miller and Morton, 1977). In addition, chemical and petrographic similarities and field relations show that the intrusive and extrusive phases are comagmatic. Fanglomerate units and interbedded basalt flows of middle to late Miocene age unconformably overlie the mid-Tertiary silicic magmatic rocks. These are in turn overlain by the early Pliocene marine Bouse Formation and several Plio-Pleistocene alluvial units.

The major structural feature in the Chocolate Mountains is the CMT. The Chocolate Mountains form a broad antiform with Orocopia Schist in the core flanked by the CMT and upper plate rocks. Low angle detachment faulting is also probably present in the range. The tilting of Tertiary volcanic rocks 20 to 40° to the southwest near Mesquite has led some to interpret the presence of a detachment fault there. Dating of the CMT in the southern Chocolate Mountains yields reset K-Ar ages of 22.6 $\pm$ 0.7 m.y. (WR) just below the thrust, 37.4 $\pm$ 3.7 m.y. (biotite) at 30 cm below the thrust, and 53.6 $\pm$ 6.4 m.y. (biotite) at 100 meters below the thrust (Frost et al., 1982). At least in places, the CMT has been reactivated by detachment age and style of faulting. Northwest-trending faults with right-lateral offsets which are parallel to the San Andreas Fault and northeast-trending high angle faults cut rocks of various ages.

Gold mineralization occurs along a low angle, brecciated structural zone at Mesquite. This structural zone dips to the southwest and has been interpreted by different people to represent the CMT or a detachment fault. 2.7

55.3 High peaks at 11:00 are Mt. Barrow. This is the locality of the quartz monzonite of Mount Barrow (Dillon, 1975). This is a hornblende-biotite quartz monzonite stock dated at 20.5 m.y. (hornblende and biotite, Miller and Morton, 1977). 1.5

56.8 Low hills on right held up by moderately consolidated brown breccias and conglomerates composed of basement rock clasts with subordinate clasts of volcanic rocks. This unit is Tertiary in age and has been faulted, tilted, and locally folded. 3.0

59.8 Old placer workings in wash on right. 0.7

60.5 Intersection of State Highway 78. Turn left (west) and proceed toward Glamis. We are driving through exposures of altered, maroon-weathering pyroxene rhyodacite to andesite lava flows of the Quechan volcanics and partially welded to unwelded, pink, pumiceous crystal tuffs unconformably overlying the Quechan volcanics. 1.4

61.9 Crossing the pre-Columbian Indian Trail which led from the Colorado River to Lake Coachuilla (now Imperial Valley). On the right hand side of the road is the Crown uranium occurrence (ruins barely visible). Doctors from El Centro used to bring patients here by bus where they were seated in old movie seats to receive the benefits of the natural radiation. 0.4

62.3 Gables Wash -- good exposures of the CMT are present about one half mile up the wash. 0.3

62.6 Quechan volcanics tilted 20° to the southwest along right side of road. 0.4

63.0 Overview of Gold Fields Mining Corp.'s Mesquite mine (Fig. 3).

THE MESQUITE MINE

In November 1982 Gold Fields Mining Corp. announced a discovery at its Big Chief property in Imperial County, California. Reserves were stated at 26 million tons at a grade of 0.075 oz/ton gold or 41.5 million tons at a grade of 0.056 oz/ton gold. In November 1985 Gold Fields announced the start of crushing operations at its Mesquite gold mine and stated that the first gold production was anticipated by the end of February 1986. Mineable reserves were given as 38 million tons grading about 0.05 oz/ton gold. Three new deposits near the main deposit were discovered by recent drilling and have added an additional 15 million tons averaging 0.05 oz/ton gold to the reserves. These new deposits occur south of the highway and include the old Vista and Rainbow mines.

There has been no published data on the Mesquite deposit. However, the Society of Economic Geologists conducted a trip to Mesquite on February 24, 1984. The following discussion is based on information provided by Gold Fields personnel at that time.

The orebody currently under development is 2,200 feet in a WNW direction by 1,200 feet in an ENE direction and averages 170 feet thick (maximum thickness is 300 feet). The orebody is shaped like a flattened pear and dips gently to the west at 20°. The Big Chief shaft marks the SE corner of the orebody and the linear nature of the SW margin of the orebody is the result of a WNW-trending, nearly vertical fault.

The rocks in the mine area are considered to be Chuckwalla Complex (Precambrian) and consist of biotite gneiss, a "mylonite" breccia (microbreccia) zone, and muscovite schist. These are the same rocks mapped as banded gneiss by Dillon (1975). Most of the deposit is covered by 10 to 200 feet of recent gravels.

The majority of the mineralization occurs in the breccia zone with minor amounts in the schist. The footwall of the breccia, or "mylonite", zone is an assay wall. There is a weak, positive correlation of

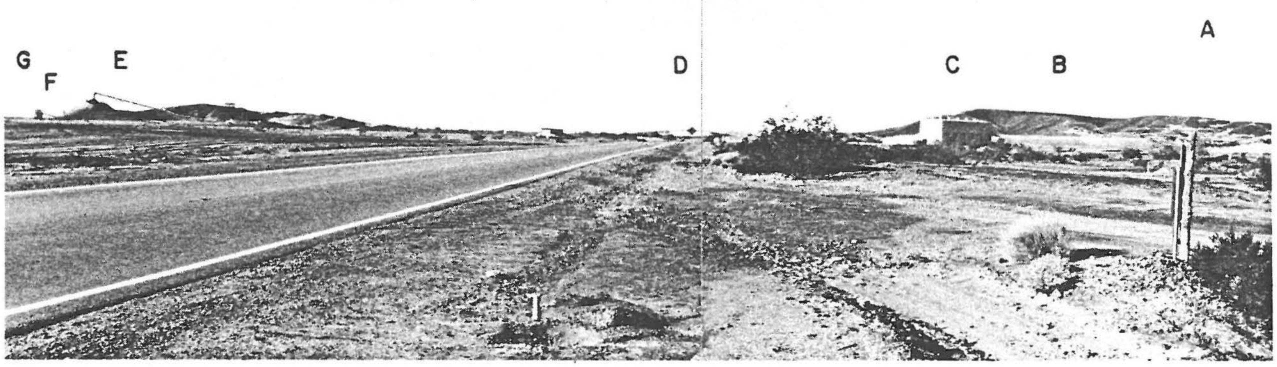


FIGURE 3. Overview of Gold Fields Mining Corporation's Mesquite gold mine near Glamis, Imperial Co., California. A- drill roads near Big Brother workings. B- pit is located behind heap leach test pads. C- mine shop and office buildings. D- ore conveyor overpass. E- coarse ore stockpile. F- fine crushing and agglomeration facilities. G- leach pads. Photo is taken looking southwest towards Glamis.

gold with sulfides, thus the target is the sulfide package, now mostly oxidized.

There is a higher grade zone in the center where the orebody is the thickest. Grades are somewhat more erratic outside of this zone. A hole was drilled to 1,500 feet in the center of the deposit passing through the ore zone and into what Gold Fields calls Precambrian rocks with no gold values. Once below the zone of oxidation, which extends to 400 feet, sometimes 500 feet, the rocks are barren.

According to Gold Fields, the orebody does not contain much stockwork veining but consists of randomly oriented fractures. There is a pegmatite association with ore, but it is not known if the association is genetic or only spatial. It is known that pegmatites are mineralized only where they are fractured. Mafic dikes occur in the area, but not in the ore zone. To the Gold Fields geologist, ground preparation is the main ore control.

The Mesquite deposit is a low silver, high gold deposit (gold to silver ratio of 3 to 1). Gold occurs as free gold along microfractures in the oxidized zone. There is no enrichment of gold at the oxide-sulfide boundary, although recent fractures have redistributed some gold. Pyrite is the dominant sulfide with traces of chalcopyrite, sphalerite, galena, and gersdorffite (NiAsS). Cinnabar and carnotite have also been reported.

There is no silicification, either pervasive or veinlet-controlled. There is a positive correlation of gold with carbonate (both clear and brown calcite, not siderite) and there is a high carbonate zone in the decline which assayed up to 3 oz/ton gold. The carbonate occurs as breccia cement and in veins and veinlets. Metallurgical testing indicated the presence of up to 30% clays in some ores and sericite has been observed. Adjacent to some of the carbonate veinlets biotite has been altered to chlorite. Magnetite and fluorite are not present.

The low angle breccia or "mylonite" zone that hosts the orebody is perhaps the most significant structural element. High angle structures displace low angle structures and both are mineralized. Gold Fields believes the high angle structures are related to the San Andreas Fault. The low angle faults are not believed to be detachment faults because of the way they steepen and roll. The breccia zone containing the mineralization occurs on the north limb of an east-west trending syncline defined by foliation. Shearing and faulting in most cases are parallel to foliation.

By the extension of known structures, alignment of mineral occurrences, and observations of where Gold Fields is drilling, it is apparent that there is a WNW structural zone along the front of the Chocolate Mountains that is thought to be Gold Fields' main target. The nature of the orebody discussed and the distribution of drilling in the immediate area of Mesquite suggest that ore grade mineralization occurs in discrete pods along the structural zone.

Geochemical data for Mesquite are scarce. It is reported that the mineralization is anomalous in arsenic. In fact, prior to development some of the water wells contained abnormally high arsenic levels. Base metals and antimony are reported to be very low. Anomalous uranium values are present and Mesquite is reported to be an airborne radiometric anomaly.

The origin of the deposit is the subject of much speculation. There appear to be four main models currently in vogue: 1) mineralization related to Laramide age peraluminous-calcic pegmatites and alaskites; 2) a syngenetic, stratabound genesis; 3) ground preparation along the Chocolate Mountains thrust with mineralization occurring later; and 4) mineralization related to detachment faulting. 0.5

63.5 Zapponi Road turnoff, leads to Rainbow pit near dumps with tank on top. Based on drill pattern, Gold Fields has made a discovery in this area. 0.9

64.4 Note cuttings piles on left. Drill pattern suggests Gold Fields has made a discovery in this area. 0.4

64.8 Stop 2. Turn to right to Dick and Ann Singer's trailer. There will be a brief overview of the Mesquite operation from here. 0.3

65.1 Mesquite mine shop on right, ore stock pile and leach dumps on left. 0.2

65.3 Ore conveyor overpass. 0.2

65.5 Cross wash, Gold Hill on right. This will eventually be the eastern limit of the main pit. 0.1

65.6 Mesquite mine sign. 0.3

65.9 Waste dumps on right. Turn around and return to Ogilby Road, turn right (south) and proceed to the American Girl Mine Road. 25.7

91.6 American Girl Mine Road, turn left and stay on main road. 1.0

92.6 Road to the right leads to old mill used to concentrate kyanite. The only known commercial deposits of the aluminum silicate kyanite, Al_2SiO_5, lie at the southwestern front of the Cargo Muchacho Mountains near Ogilby in southeastern Imperial County. Here, blue kyanite crystals occur with quartz in large masses associated with quartzite and quartz-muscovite schist of the Vitrefax Formation. Ore produced was in the 15 to 35 percent range for contained kyanite. The kyanite-quartz rock was heated to a temperature of 1,800° F in a rotary kiln, quenched to cause partial separation of the two minerals, then separated more completely by crushing and screening. The kyanite concentrate was shipped to Los Angeles and used in the manufacture of ceramic insulators and high-alumina refractories which can withstand temperatures as high as 3,300° F and abrupt temperature changes. Such conditions occur in special furnaces, kilns, and boilers used in the glass, ceramic, cement, and metallurgical industries (Morton, 1977). 0.1

92.7 Vitrefax Hill at 12:00. Cuts on the hill are from production of kyanite.

Clusters of large blue kyanite crystals occur disseminated in a quartz-kyanite quartzite of the Precambrian(?) Vitrefax Formation. Kyanite bearing rocks of this formation crop out discontinuously for more than one mile in a more or less north-trending belt along the western base of the range. Where it was mined the kyanite is in quartzite; it occurs also in quartz sericite pelitic schist, and in a pyrophyllite zone northwest of the quarry. At Vitrefax Hill wherein the quarry is located, steeply-dipping kyanite-rich quartzite as much as 400 feet thick forms the core of the hill, but interbedded quartz sericite schist is present on the flanks. The beds strike generally northeast. The material which has been mined is composed of about 35 percent kyanite with quartz comprising most of the remainder. Disseminated small grains of rutile, specular hematite, magnetite, biotite, and chlorite are present also; limonite pseudomorphs after pyrite, as much as 1 inch square, are present in the face of one of the quarries. Virtually all of the rock contains more than 15 percent kyanite (Morton, 1977). 1.3

94.0 Bear to left of Vitrefax Hill. 0.8

94.8 Road bears right toward American Girl Canyon. Cuts on right from kyanite production. 0.3

95.1 Enter American Girl Canyon. 0.2

95.3 Cuts on right in sericite-kyanite schist of Vitrefax Formation. 0.1

95.4 Old mill buildings. 0.1

95.5 Locked gate. We will proceed from here to the American Girl mine with a representative of Newmont Exploration, Ltd. 0.9

96.4 Stop 3. American Girl mine. Newmont Mining Corp. controls the American Girl and Padre-Madre mine areas. Little information has been made public regarding their activities. Through an extensive drilling program of 1,200 holes (Chavez, 1985), Newmont has outlined a reserve of 300,000 ounces of gold in the American Girl and Padre-Madre areas.

AMERICAN GIRL MINE

The following descriptions are taken from Morton (1977). The American Girl mine was located in 1892 and was mined continuously until 1900. Little or no additional mining was done thereafter until the period 1913-1916. From 1913-1936 the mine was idle but from 1936-1939 about 150,000 tons was mined valued at $900,000 ($35 per ounce). The mine has been idle through 1962. Total estimated production is 205,000 tons valued at $1,285,000.

Development consists of two single-compartment inclined shafts 740 feet and 850 feet deep. The American Girl shaft, the original working shaft, was sunk in the footwall of the Brown vein at an incline of 35 degrees in the upper levels and 25 degrees in the lower part. The Tybo shaft, about 800 feet west of the first shaft, was sunk at a similar inclination to an 850-foot depth. Main levels were developed at 100-foot intervals to the 700 level; the lowest is the 740 level. Total main level horizontal workings exceed 8,700 feet.

Three essentially parallel veins occur that strike nearly due east and dip 25-70 degrees south in Tumco Formation arkosite. The east end of the veins swing slightly to the north. Tumco arkosite is composed of fine- to medium-grained, gray, highly indurated metasediments made up of quartz and feldspar with minor hornblende and biotite. Relict bedding is apparent in minor compositional changes, banding, and interbedded thin layers of green-gray hornblende schist. Biotite granite crops out a few hundred feet south of the veins on the surface, and its contact with arkosite bears generally parallel to them, but transects them in the eastern parts of the mine.

The veins are designated from north to south the Blue, White, and Brown veins; the latter is the principal one. It dips 25-35 degrees south, apparently parallel to the relict bedding in arkosite. The Brown vein ranges in width from a few feet to as much as 40 feet. It has been mined along the strike a distance of 1,500 feet and to an inclined depth of 850 feet. Maps of the stoped areas indicated an apparent rake of the main orebody to the west.

The veins include the following primary ore minerals: gold, native silver, chalcopyrite, covellite, chalcocite, bornite, galena, and sphalerite. Secondary ore minerals include azurite, malachite, cuprite, native copper, and chrysocolla. Gangue minerals noted were quartz, pyrite, calcite, sericite, chlorite, biotite, fluorite, magnetite, hematite, and hydrous iron oxides. Anomalous radioactivity amounting to five times normal background count has been noted in the mine. Above the 250-foot level the gold occurs free but below that it occurs both free and enclosed in grains of pyrite and chalcopyrite. Most of the gold was -325 mesh.

Wall rocks have undergone intense sericitization, chloritization, and feldspathization for several tens of feet away from the veins. Where biotite granite is present, as in the far eastern parts of the vein, only chloritization is prevalent.

The Blue vein is about 200 feet north of the Brown vein and strikes parallel to it but dips more steeply (70 degrees south). The White vein is between the Blue and Brown veins and also dips 70 degrees south but strikes more to the northeast so that it intersects both of the other two veins. The Blue and the White veins apparently were mined only in their upper levels and the records are obscure as to their exact nature. At the bedrock surface these veins are obscured by alluvium.

Return to vehicles and retrace route. 1.4

97.8 Take diagonal road to left. 0.2

98.0 Bear right. 0.1

98.1 Cross small wash. Light colored dumps at 8:00 along trace of thrust fault (Dillon, 1975). 0.1

98.2 Old foundations, evidence for drilling at 9:00. 0.2

98.4 Intersect well-graded road, turn left around Vitrefax Hill. 0.1

98.5 Bear left across wash. 0.1

98.6 Fork in road immediately across wash, bear left. 0.1

98.7 Beginning of Newmont drilling in Padre-Madre Canyon. 0.2

98.9 Road curves to right. 0.1

99.0 Note iron-stained rocks in outcrop at right. 0.05

99.05 Road intersection, proceed straight ahead. 0.05

99.1 Bear left. 0.3

99.4 Bear left. 0.1

99.5 Stop 4. Padre-Madre pit. Park vehicles here. Visible gold can be found by breaking iron-stained rocks in the pit.

PADRE-MADRE MINE

The following discussion of the Padre-Madre mine is taken from Morton (1977). This deposit was one of the earliest discovered in Imperial County. It was reportedly worked by the Spanish settlers of Yuma in 1780-81. Most of the development apparently took place prior to 1890. Development consists of several vertical shafts, the deepest of which are 325, 300, and 250 feet. The extent of the stoping is undetermined but reportedly extends several hundred feet along the strike. Numerous cuts dot the surface. Two poorly exposed sub-parallel veins occur in quartz diorite gneiss. The veins strike mostly N 10-30° W but are reported to range from N 50° W to N 50° E. The dips are quite variable also but in general are between 20° and 60° SW and NE. In some exposures the veins appear to be parallel to the foliation. The two veins, designated the Padre y Madre, are about 300 to 500 feet apart. Scheelite in undetermined amounts has been reported present.

Mineralization in the American Girl and Padre-Madre areas is reported to contain more base metals than the mineralization at Mesquite. Gold to silver ratios are approximately 1 to 1 and arsenic and antimony values are low.

As at Mesquite, the genesis of the deposits in the Cargo Muchachos is a controversial subject. Several models have been suggested: 1) thrust fault-related with multiple veins representing stacked thrusts; 2) detachment fault-related with multiple veins representing stacked detachments; 3) mineralization related to Laramide age peraluminous-calcic pegmatites and aplites. Keith (pers. comm.) feels the ore deposits in the Cargo Muchacho Mountains represent a more differentiated, more oxidized, base metal rich end member of mineralization compared to that at Mesquite; 4) a syngenetic, stratabound genesis; and 5) genetically related to Jurassic igneous rocks with the possibility of some remobilization during Mesozoic or Tertiary deformation (Tosdal et al., 1985).

Turn around and retrace route. 0.4

99.9 Bear left on well-graded road. 0.3

100.2 Bear left along south side of Vitrefax Hill. 0.3

100.5 Cross under power line and bear right into wash at road intersection. 0.25

100.75 Intersection with American Girl Mine Road. Return to Ogilby Road and turn left. Return 19.6 miles to Yuma. Remember to take the 4th Avenue exit from the interstate in Yuma.

END OF DAY 1.

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FIELD GUIDE TO THE CHOCOLATE MOUNTAINS THRUST AND OROCOPIA SCHIST, GAVILAN WASH AREA, SOUTHEASTERNMOST CALIFORNIA

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INTRODUCTION

Chocolate Mountains thrust and Orocopia Schist: Summary

The late Mesozoic Orocopia Schist is the structurally lowest tectonostratigraphic unit exposed in the southeastern California-southwestern Arizona region. The metamorphosed oceanic sedimentary and volcanic rocks of the schist are overlain, along the regionally extensive Chocolate Mountains and Orocopia thrusts, by a slab or flake of continental crust (Haxel and Dillon, 1978).

The Orocopia Schist and Chocolate Mountains thrust are very similar to the Pelona Schist and Vincent thrust, exposed in the central Transverse Ranges of southern California (Ehlig, 1981). Prior to displacement on the Neogene San Andreas fault system, the two schists and their overlying thrust faults were adjacent to one another. Most of the general descriptions of and statements about the Orocopia Schist and Chocolate Mountains thrust in this guide apply to the Pelona Schist and Vincent and Orocopia thrusts as well.

The dominate lithology within the Orocopia Schist is quartzofeldspathic to semipelitic schist derived from sandstone. Minor rock types are metabasalt, ferromanganiferous metachert and siliceous marble, and rare ultramafic rocks. This trip will examine metasandstone (Stop 10), metabasalt (Stop 12), metachert (Stop 11), and one of the few serpentinite bodies in the Orocopia Schist (Stop 13). Within the region of this field trip, rock types other than metasandstone constitute less than 1% of the schist.

Fabric relations within the Chocolate Mountains thrust zone (Stops 4-8) and inverted metamorphic zonation in the underlying Orocopia Schist indicate that the thrust is synmetamorphic with respect to the schist (Ehlig, 1958, 1981; Dillon, 1976; Haxel, 1977; Jacobson, 1983a,b; Graham and England, 1976).

Unlike the lower-plate Orocopia Schist, whose metamorphism is related to the Chocolate Mountains thrust, the rocks of the upper plate of the thrust are only incidentally associated with it, in that they represent an apparently random slice through a piece of preexisting Proterozoic and Mesozoic continental crust. The regional and local heterogeneity and long and complex geologic history of the upper-plate terranes (Powell, 1981; Silver, 1982; Dillon, 1976; Ehlig, 1981) contrast with the lithologic uniformity and apparent monometamorphic character of the lower-plate Orocopia Schist. This strong contrast in lithology and geologic history across the Chocolate Mountains thrust, together with its regional extent, suggest a corresponding large displacement, probably at least several tens of kilometers.

The basin in which the protolith of the Orocopia Schist was deposited, and at least part of the protolith itself, are older than 163 m.y. (Mukasa and others, 1984). Metamorphism of the schist and movement on the Chocolate Mountains thrust evidently occurred between about 87 and 74 m.y. ago (Ehlig, 1981; Walker and May, 1986; Dillon, 1986; Mahaffie and Dokka, 1986; Haxel and others, 1985).

The origin and significance of the Orocopia Schist and Chocolate Mountains thrust represent a persistent problem in our understanding of the late Mesozoic tectonic evolution of the southwestern Cordillera (Crowell, 1981; Burchfiel and Davis, 1981; Haxel and Dillon, 1978; Jacobson, 1983a; Vedder and others, 1983). Several tectonic models have been proposed, but recently acquired data argue, more or less strongly, against all of them. In particular, the Orocopia-protolith basin evidently is at least 80 m.y. older than the metamorphism of the schist. This implies that two separate models are required: one for the formation of the Jurassic(?) oceanic protolith basin, and another for the Late Cretaceous subduction or collision episode in which the protolith was overthrust by continental crust and metamorphosed to produce the Orocopia Schist.

The field trip

Many segments of the Chocolate Mountains and related thrusts are modified by younger deformation, not well exposed, too remote for a one-day excursion, or within areas of restricted access. In the area described in this guide, a segment of the Chocolate Mountains thrust unaffected by younger deformation is well exposed in a desert environment, and is readily accessible.

The part of the Orocopia Schist examined on this trip lies within 1 km of the overlying Chocolate Mountains thrust, and is therefore not entirely representative of the schist as a whole (see Stops 4, 6, and 10). Furthermore, metabasalt, metachert, and siliceous marble are less abundant here than in most of the Orocopia Schist.

The area of the field trip is in the southeasternmost corner of California, about 80 km west of El Centro, California and 35 km north of Yuma, Arizona. Although the trip begins on the eastern edge of the Quartz Peak, California 15' quadrangle, all of the Stops are in the southwestern corner of the Picacho SW, California-Arizona 7.5' quadrangle (scale 1:24,000). Aspects of the regional geologic framework are described by Olmsted and others (1973),

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Crowe (1973), Dillon (1976), Morton (1977), Haxel (1977), Crowe and others (1979), Haxel and others (1985), and several papers in the volume edited by Frost and Martin (1982b).

The field trip involves a hike of about 4 km. Elevation gain is only about 150 m, chiefly between Stops 3 and 7. Along the rest of the traverse, relief is very low. Normal time for the whole trip, including all 14 Stops but excluding driving time to and from Gavilan Wash, is about 6 or 7 hours. The trip might be done hurriedly in as little as 5 hours, especially if Stops 8 and 9, which require a detour from the main route, were skipped. A short trip to the Chocolate Mountains thrust (Stops 1-9 or 4-9 only), without continuing to the Orocopia Schist (Stops 10-13) might be completed in about 3 hours. With a large group and adequate time for discussion, the trip, including the drive into and out of Gavilan Wash, requires (and deserves) an entire winter day.

If it is windy in Gavilan Wash, it is likely to be considerably windier along much of traverse.

Directions for driving to beginning of field trip

1A. From Interstate 8 about 13 miles west of Yuma, take the Ogilby Road exit. Go north on Ogilby Road (Imperial County road S34, paved) 12.9 miles to the junction with the Indian Pass road, a graded gravel road that leads off to the northeast. There is (usually) a stop sign at the junction.

1B. From California 78 between Blythe and Brawley, turn south on the Ogilby Road and go 11.1 miles to the junction with the Indian Pass road.

2. On the Indian Pass road, drive 8.6 miles (from the junction with the Ogilby Road) generally northeastward to Indian Pass. The pass is obvious. From the pass descend about 0.5 miles to Gavilan Wash.

3. Turn right (downstream) and follow the road in the wash for about 1.2 (±0.05) miles. (This road is heavily enough used that it is normally passable with two-wheel drive). Look for a steep vehicle track ascending the south side of the wash. With four-wheel drive, drive up this track to the terrace above the wash and park there; otherwise park in the wash (don't block the public road) and walk up onto the terrace.

DIRECTIONS TO AND DESCRIPTIONS OF FIELD TRIP STOPS

The symbol >>> designates directions for walking from one Stop to the next.

Stop 0: Orientation; the Gavilan Hills

Orientation before beginning the traverse: Gavilan Wash drains eastward to the Colorado River through the middle of a low area underlain by nonresistant purplish sedimentary strata and bounded to the north by rugged peaks of Tertiary volcanic rocks. The lower hills to the south, informally called the "Gavilan Hills", are composed largely of Orocopia Schist. On the north side of the Gavilan Hills is a moderately north-dipping segment of the Chocolate Mountains thrust (Figs. 1, 2). There are two small klippe of the thrust on top of the Gavilan Hills, but these are not visible from this low vantage point.

The crystalline rocks of the Gavilan Hills are separated from the sedimentary rocks to the north by the east-west trending Gatuna fault (Stop 2). A northwest trending fault (which passes near the parking spot) offsets the Gatuna fault and Chocolate Mountains thrust (Fig. 1).

>>> Stops 1 and 2 examine a stratigraphic unit and a fault that are only indirectly related to the Chocolate Mountains thrust and Orocopia Schist but must be crossed to reach the thrust and schist.

>>> From the south side of Gavilan Wash at the locality described in the driving directions (Stop 0), walk southeast across an area of low hills and narrow arroyos underlain by purplish argillitic to phyllitic rocks and, locally, terrace gravels. Don't yet start to climb up onto the higher ground to the south underlain by crystalline rocks. Stop 1 can be made anywhere in the vicinity of the locality shown in Figure 1.

Stop 1: Winterhaven Formation

These generally purplish, fine-grained, slightly or somewhat metamorphosed clastic sedimentary rocks belong to the argillitic siltstone member of the Jurassic(?) Winterhaven Formation (Haxel and others, 1985). The principal lithologic type within this unit are massive, dark-purple to dark-brown, slightly calcareous argillitic siltstone (micrograywacke); silty argillite; and medium- to very- coarse-grained graywacke. Less common rock types are sandy limestone, argillitic sandstone, and quartzite-pebble conglomerate.

Although the age of the Winterhaven Formation has not been determined directly by paleontologic or isotopic means, its relations to other units indicate a Jurassic age. At its base, the formation evidently is interbedded with pre-165 m.y. metavolcanic rocks of presumed Early or Middle Jurassic age. Volcanic and sedimentary rocks similar to those of the Winterhaven Formation are intruded by Middle or Late Jurassic granitic rocks.

The Winterhaven Formation originally occupied a high structural level within the upper plate of the Late Cretaceous Chocolate Mountains thrust. The formation was subsequently displaced structurally downward, and in some areas placed directly atop the Orocopia Schist (the lower plate of the thrust), by movement along a Late (latest?) Cretaceous low-angle normal fault. Relations between the Winterhaven Formation and Orocopia Schist were then further complicated by intrusion of latest Cretaceous granite and by middle and late Tertiary low- and high-angle normal faulting.

>>> Continue southeast toward the prominent fault contact between the low, purplish Winterhaven Formation hills to the north and the higher ridges of crystalline rocks to the south.

Stop 2: Gatuna fault

In the Gavilan Hills area, the contact between the Winterhaven Formation and the crystalline rocks of the upper and lower plates of the Chocolate Mountains thrust is the Gatuna fault. This fault is fairly well exposed in several arroyos at Stop 2. It is marked by a meter or less of gouge, and dips moderately to steeply northward. The Gatuna fault is of middle or late Tertiary age, as it forms part of a

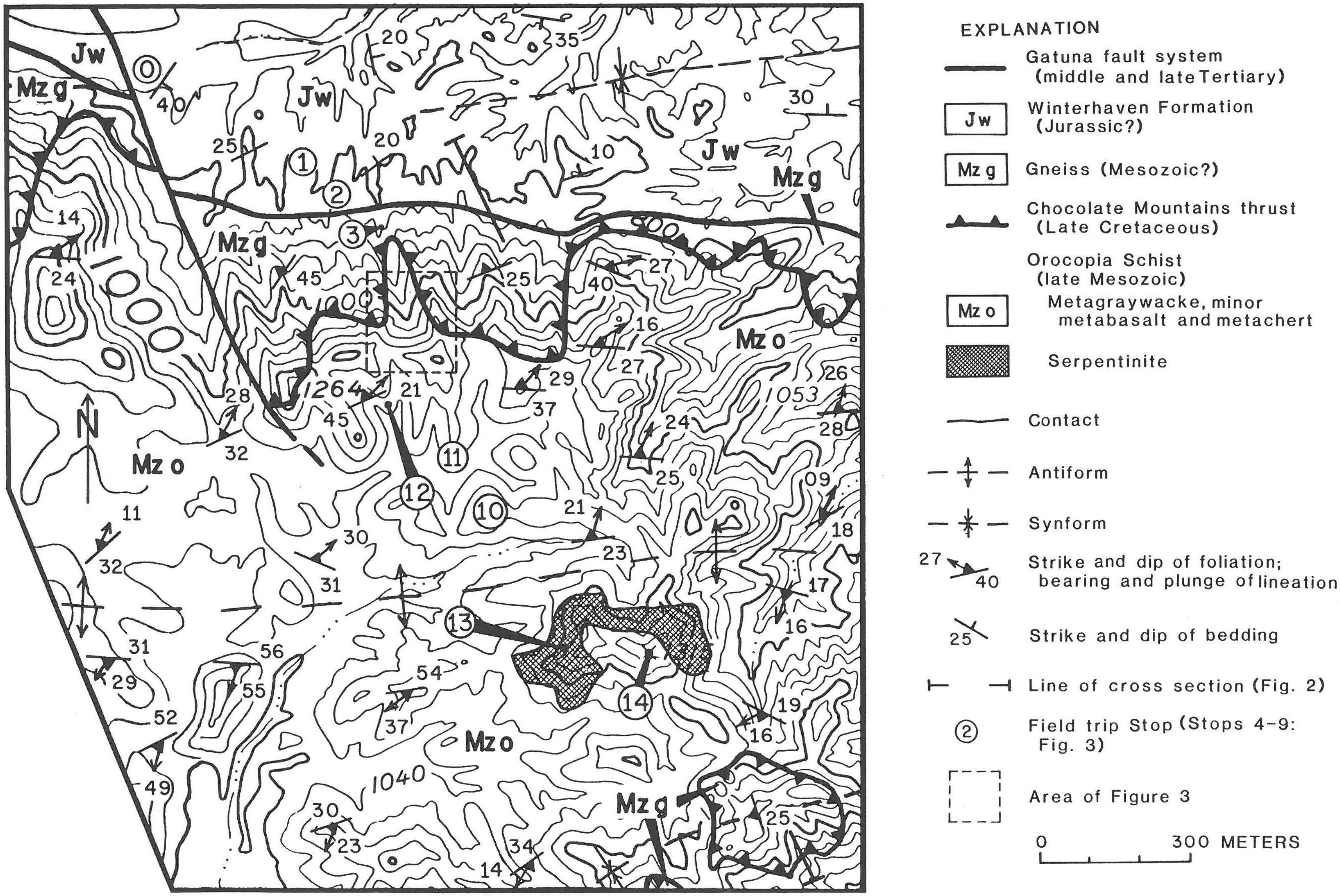

Figure 1. Geologic map of the field trip area, with locations of Stops 0-3 and 10-14. Rectangle in north-central part of this map indicates area of larger scale map, Figure 3, on which locations of thrust-zone Stops 4-9 are shown. Map from Haxel (1977, Plate 1-1,1-2). Quaternary terrace gravel deposits in the northwest corner of the map area are omitted. Base map from Picacho SW, California-Arizona 7.5' and Quartz Peak, California 15' quadrangles.

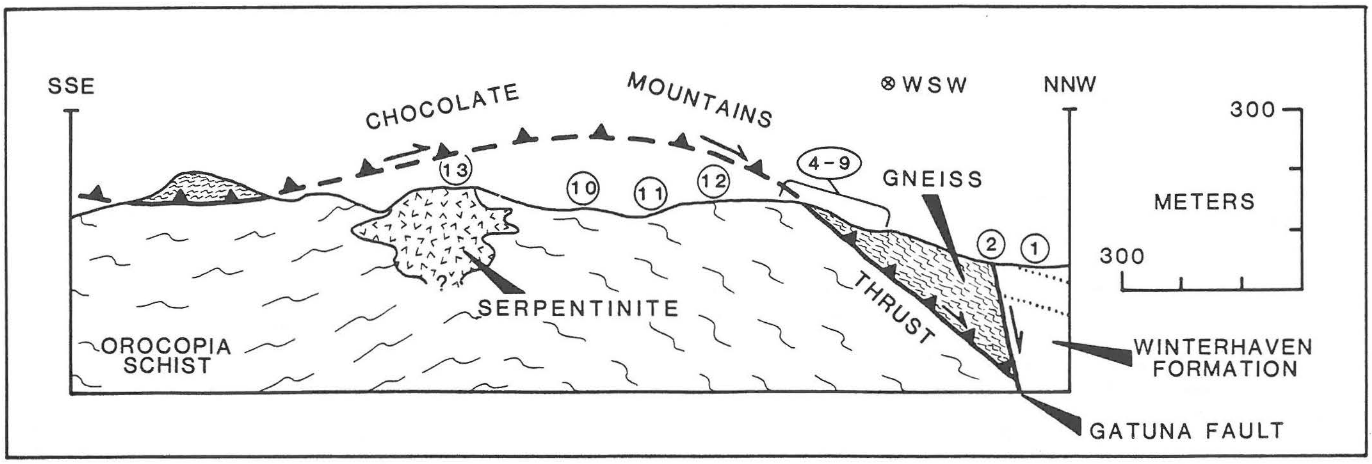

Figure 2. Cross section of the Chocolate Mountains thrust and Orocopia Schist; line of section (Fig. 1) is subparallel to field trip traverse. Encircled numbers indicate approximate positions of most field trip Stops, projected into section. For ages of rock units, see Figure 1.

larger fault system that cuts Oligocene and Miocene volcanic rocks. Regional patterns of Tertiary extensional structures suggest the Gatuna fault is a "breakaway fault" that separates extensionally deformed terrane to the north from the apparently unextended area of the Gavilan Hills to the south (Tosdal and Sherrod, 1985). (Local prospectors have regarded the Gatuna fault as a branch of the Texas lineament!)

>>> Walk east about 150 m to the mouth of the first prominent north-draining canyon. The easiest way lies along an indistinct, discontinuous trail, worn by feral burros and geologists, that approximates the trace of the Gatuna fault. Stops 3-9 are in this canyon (Figs. 1, 3). Turn south and walk up the canyon, roughly 40 m, to outcrops of gneiss.

Stop 3: Upper plate of the Chocolate Mountains thrust

On the scale of southeastern California, the upper plate of the Chocolate Mountains thrust consists of a number of different plutonic, and subordinate supracrustal, rock units of Proterozoic, Paleozoic, and Mesozoic age (Dillon, 1976; Powell, 1981; Haxel and others, 1985).

In the Gavilan Hills and vicinity, the upper plate of the Chocolate Mountains thrust happens to be a package of heterogeneous gneissic rocks. Principal lithologic types are epidote-biotite quartzofeldspathic gneiss, with or without muscovite or hornblende; biotite-rich quartzofeldspathic gneiss; leucocratic quartzofeldspathic gneiss; pegmatoid gneiss or foliated pegmatite; and quartz-epidote amphibolite to amphibolite, locally grading to hornblendite. All of these rock types may be found in place or as float in the vicinity of Stop 3. The age(s) and origin(s) of these gneisses are uncertain. Regionally, the most reasonable possibility is that they are highly deformed plutonic rocks related to either the Jurassic granitoids of the Cargo Muchacho Mountains or the early, mafic phase of the Triassic plutonic suite of the southern Chocolate, Palo Verde, and Trigo Mountains (Dillon, 1976; Silver, 1971; Tosdal, 1986).

With respect to the Chocolate Mountains thrust, the important feature of the upper-plate rock is its gneissic layering, which clearly predates and is entirely independent of the thrust. This pre-existing upper-plate fabric is overprinted by mylonitization (Stops 5, 7) and local folding (Stop 8) within the Chocolate Mountains thrust zone. In general, the intensity of this deformation progressively increases structurally downward, through a distance of several tens of meters, toward the base of the upper plate. Rocks within this interval, such as those at Stop 3 and farther south (structurally lower), generally have hybrid fabrics--gneissic layering variably overprinted and transposed by thrust-zone mylonitization.

>>> Continue up the canyon, about 200 m, to the point where the drainage splits into several tributaries (Fig. 3). In the southeastern part of this area of confluence is a small, shiny knob of Orocopia Schist. Climb up onto this knob.

Stop 4: Overview of the Chocolate Mountains thrust zone

The Chocolate Mountains thrust itself is a planar surface, locatable to within less than a centimeter in the best of outcrops (Stops 5, 7). Straddling the thrust surface is the thrust zone, a layer of rocks that are texturally distinct from, but grade into, rocks farther above or below the thrust (Fig. 4). The thrust zone is on the order of tens of meters to one hundred meters thick. The upper-plate part of the thrust zone consists of mylonitic rocks (Stop 5). Beneath the thrust is a zone of Orocopia Schist that is notably coarser grained than, and grades downward into, the normal schist farther below the thrust. This coarse schist is typically crystalloblastic but locally protomylonitic (Stops 6, 9).

Lineation in the mylonitic rocks at the base of the upper plate, in the coarse schist beneath the thrust, and in Orocopia Schist below the thrust zone are all parallel. Metamorphic grade within the Orocopia Schist increases upward toward the thrust; in the Gavilan Hills and vicinity, the chief manifestations of this upgrading are the change from albite to oligoclase or andesine in metabasalts (Stop 12) and the incoming of garnet in quartzofeldspathic schist (Stop 6). These and others relations which indicate that the Chocolate Mountains thrust is synmetamorphic have been interpreted in terms of metamorphism of the schist during thrusting (Ehlig, 1958, 1981), metamorphism of the schist as a consequence of tectonic burial beneath the upper plate of the thrust (Haxel, 1977), or incipient subduction of the schist (Graham and England, 1976; Jacobson, 1983a).

Most of the rocks in this canyon visible from this Stop are within the thrust zone; the structurally highest (northernmost) upper-plate gneisses are near the top of or just above the thrust zone. The thrust dips about 40 degrees north-northwest; its trace forms a sharp vee pointing down the canyon. The thrust surface lies within or at the base of the conspicuous, nearly continuous, north-dipping resistant layer in the upper and middle part of the east side of the canyon.

>>> Scramble up and east or east-southeast to the base of the highest part of the small cliff near the top of the east side of the canyon (Fig. 3).

Stop 5: The Chocolate Mountains thrust; upper-plate mylonitic rocks

The thrust surface is well exposed in several outcrops within the lower meter or so of this cliff. The trace of the thrust is seen as a sharply defined horizon that separates moderately foliated mylonite above from more strongly foliated coarse-grained Orocopia Schist below. In one of these exposures, the trace of the thrust surface is particularly prominent and photogenic.

The thrust surface can be more readily located by the contrast in the weathered appearance of the less fissle upper-plate mylonitic rocks and more fissle Orocopia Schist than by hand-lens examination. Although readily distinguished in thin-section, the rocks of the base of the upper plate and those at the top of the lower plate tend to look alike in hand specimen because of their similar composition and metamorphic grade. At this locality, the distinction is also obscured by some alteration of the thrust zone rocks and by desert varnish. Field criteria that proved useful for distinguishing upper-plate and lower-plate rocks during mapping of the Chocolate Mountains thrust are summarized in the Appendix.

These readily accessible outcrops are among the best exposures of the Chocolate Mountains thrust, and are certainly the best outside the Chocolate Mountains Gunnery Range. ***** PLEASE DON'T HAMMER ON THESE OUTCROPS; PRESERVE THEM FOR OTHER GEOLOGISTS TO EXAMINE! ***** Plenty of samples of mylonite and coarse-grained Orocopia Schist are available in the fallen blocks at the base of the cliff. Oriented samples can be collected from nearby ordinary outcrops.

Mylonitic rocks in the upper-plate portion of the thrust zone include protomylonite in which gneissic layering is preserved; schistose to flinty mylonite; flinty, schistose, or semi-massive blastomylonite; and, locally, flinty, laminated ultramylonite derived from quartz-rich rocks. At this Stop, mylonite just above the thrust surface grades upward, through an interval of several meters, into protomylonite; this in turn grades upward into mixed or hybrid gneiss and protomylonite. (Terminology for fault rocks is that

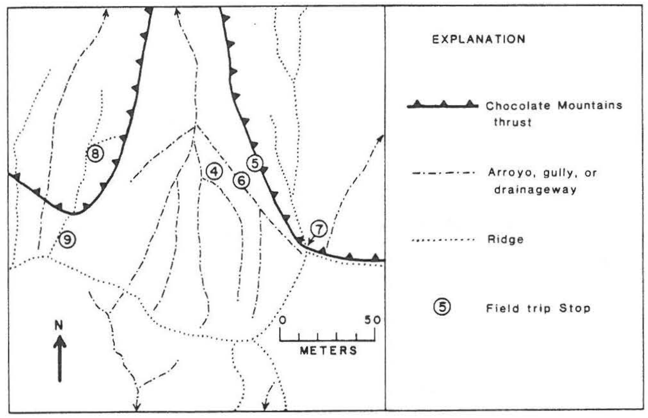

Figure 3. Sketch map showing Stops 4-9 in relation to ridges and drainageways and the Chocolate Mountains thrust. Map traced from enlarged aerial photograph; scale is approximate.

of Higgins (1971) as modified by Sibson (1977) and Wise and others (1984).) See also description for Stop 8B.

>>> Walk west or southwest (and topographically and structurally down) a few tens of meters to any good exposure of coarse-grained Orocopia Schist (Fig. 3).

Stop 6: Zone of coarse-grained Orocopia Schist

The layer of coarse-grained Orocopia Schist, typically several tens of meters thick, that makes up the lower-plate part of the thrust zone (Fig. 4) is characterized by large flakes or irregular pads, several millimeters across, of muscovite and biotite. Lineation is conspicuously weaker in the coarse schist than in normal schist farther below the thrust. The coarse schist typically appears crystalloblastic in hand specimen, but in thin section some samples are protomylonitic. Textural relations in thin section indicate that mylonitization was superposed upon and postdates crystalloblastic formation of the coarse schist. Quartzofeldspathic schist within the zone of coarse schist differs mineralogically from schist of similar composition farther below the thrust in that garnet is common and sphene and epidote are less abundant; the pleochroism of biotite is also different.

>>> The thin resistant layer along the thrust passes through a small notch in the ridge on the southeast side of the canyon (Fig. 3). Climb up and southeast to this notch.

Stop 7: Another exposure of the thrust

Exposures of the thrust on the north side of this notch, though not quite as good as those at Stop 5, are often more photogenic because of their better lighting, more apparent geologic context, and scenic background.

From this notch the trace of the thrust runs eastward a few hundred meters along the drainage divide between the steep gneissic ridges to the north and the gentler hills of Orocopia Schist to the south.

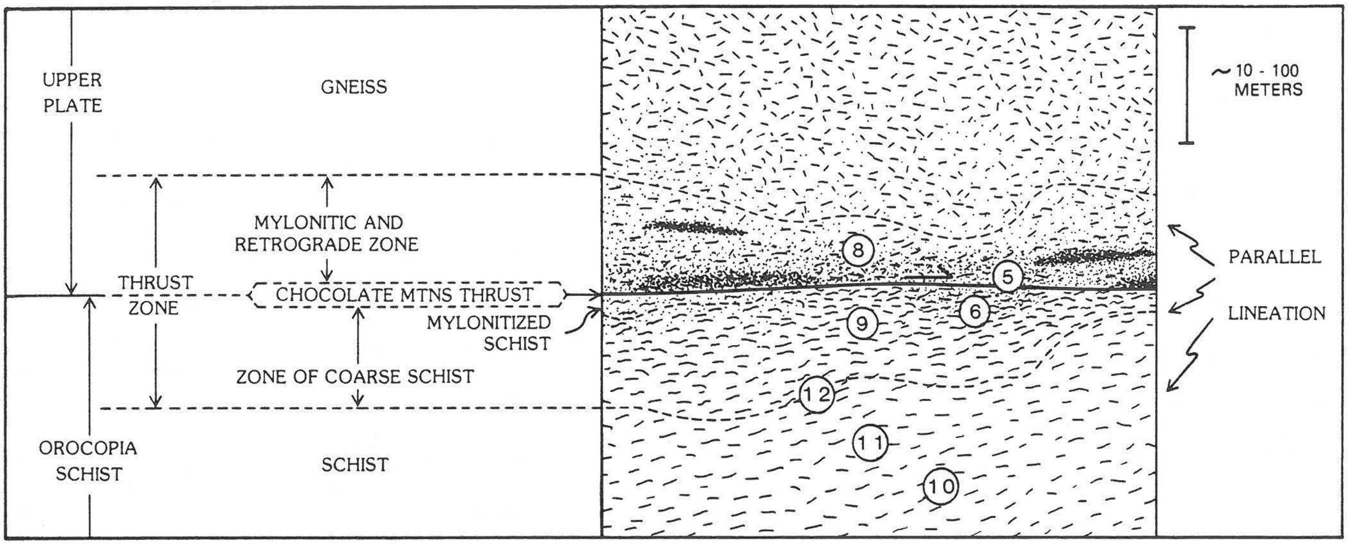

Figure 4. Schematic cross section of the Chocolate Mountains thrust zone, showing characteristic tectonic stratigraphy. The approximate position of some of the Stops within or in relation to the thrust zone is shown schematically. The thrust surface is straddled by the thrust zone, which includes all rocks of both upper and lower plate that are texturally distinct, in the field, from rocks farther above or below the thrust. Stippling represents mylonitic rocks. Dashed contacts are gradational.

>>> Stops 8 and 9 involve a short detour, to the ridge on the other side of the head of this canyon. These two Stops feature folds and microfabrics that indicate direction of movement along the Chocolate Mountains thrust, and an overview of the portion of the thrust zone examined at Stops 4-7. If Stops 8 and 9 must be omitted, proceed to the walking directions following the description of Stop 9.

>>> To proceed to Stop 8: Walk southwest then west along a burro trail that crosses the north-facing dip slope of Orocopia Schist at the head of the canyon; this trail leads to a broad drainage divide on the southwest side of the canyon (Fig. 3). From here, walk north along the ridge that forms the west side of the upper part of the canyon. About 60 m northward along its length, at an area of gently north-dipping gneiss, the ridge splits into several smaller ridges (Fig. 3). Search this area for some of the several dozen outcrop-scale folds.

Stop 8A: Asymmetric Folds in the Chocolate Mountains thrust zone

The folds at this locality fold pre-thrust gneissic layering only slightly affected by thrust-zone deformation; elsewhere in the thrust-zone strongly mylonitized rocks are folded. Thrust-zone folds range in profile from monocline-like through open and tight to isoclinal. This sequence of styles appears to represent preservation of various stages in the progessive development of the folds. Folds are typically confined to a discrete interval within the gneissic or mylonitic layering, with layers on either side of this interval not folded. Within the folded layer, fold amplitude typically decreases in either direction from an area of maximum amplitude.

Some of the thrust-zone folds consist of only a single fold hinge or are complex folds with three, four, or more hinges. Many of them, however, are fold pairs. Most of these fold pairs are markedly asymmetric and have a definite local (outcrop-scale) sense of rotation or vergence (Bell, 1981). Although the sense of asymmetry of folds at any one locality does not fully constrain the movement direction along the Chocolate Mountains thrust, the collective asymmetry of folds from many localities does uniquely indicate the direction of overthrusting (Haxel, 1977; Dillon, 1976).

In the course of mapping the Chocolate Mountains thrust, a total of 76 individual fold-pairs with an unambiguous sense of asymmetry were found, at 37 localities separated by as much as 60 km. Fifty-eight of these folds are in the upper plate and 18 in the Orocopia Schist. Six of the folds are at this locality, Stop 8. On a lower-hemisphere plot showing the fold-axis orientation and sense of asymmetry of the thrust-zone folds, Z folds plot northwest and S folds plot southeast of a northeast-southwest (038-218) striking subvertical plane of overall monoclinic symmetry. The only movement direction consistent with the collective asymmetry of the thrust-zone folds is northeastward overthrusting.

It is important to note that this method of inferring movement direction (Hansen, 1967) is a kinematic arguement based solely on symmetry, and is independent of and avoids assumptions about the mechanism(s) of folding. The folds evidently represent minor flow irregularities within the thrust-zone; their collective asymmetry necessarily reflects the overall direction of the flow that created them.

The northeastward inferred direction of overthrusting is not altered significantly by corrections for horizontal-axis rotation during Tertiary faulting and folding.

Paleomagnetic data indicate that part of the region where the thrust-zone folds used to infer movement direction occur has been rotated 40±15 degrees clockwise about a vertical axis during Neogene time (Costello, 1985). Although the paleomagnetic data are straightforward, the structures responsible for rotation have not identified. The extent and magnitude of Tertiary vertical-axis rotations in the remainder of the region are unknown. Thus, the northeastward inferred direction of overthrusting may well have originally been northward, but several questions remain to be answered.

>>> Climb to a point with an unobstructed eastward view of the bottom and east side of the canyon.

Stop 8B: Far view of the thrust zone

Most of the thrust zone (Stops 4-9) can be seen from this vantage point. The thrust surface is within or at the base of the conspicuous, nearly continuous, resistant mylonitic layer that separates the blocky weathering upper-plate gneiss and derivative mylonitic rocks from the less resistant, shiny, coarse-grained Orocopia Schist beneath the thrust.

Also visible on the east side of the canyon, within the upper plate of the thrust, is an angular interface between two thrust-zone fabrics. Below this interface is the moderately north-dipping mylonitic fabric within the resistant layer along the thrust surface. The gently to moderately north-dipping fabric above the interface is gneissic layering partially overprinted by thrust-zone mylonitization. The geometric relation between these two fabrics suggests rotation of the marginal part of the thrust-zone shear zone toward parallelism with the more strongly mylonitic central part of the shear zone (Ramsay, 1980). The sense of rotation implied by this interpretation of the asymmetric angular relation between the two thrust-zone fabrics is compatible with top-to-the-northeast shear, but not with the opposite sense of overthrusting.

>>> Walk south along the ridge; that is, retrace the route taken to reach Stop 8A. Cross the thrust and reenter the Orocopia Schist. In the vicinity of the Stop 9 locality shown in Figure 3, find one of several outcrops of coarse-grained Orocopia Schist with shear bands.

Stop 9: Thrust-zone microfabrics

Several types of asymmetric microfabrics or microstructures (Simpson and Schmid, 1983) within the thrust zone at and west of this locality indicate northeastward overthrusting. These have been studied in outcrop, hand specimen, and thin section (Tosdal, unpublished data).

In the coarse-grained Orocopia Schist at this locality, layers of high shear strain, characterized by shear bands or C' fabrics, alternate with layers of low shear strain, which contain C-S fabrics.

Further examples of composite planar fabrics and additional microstructural directional indicators, chiefly asymmetric porphyroblasts and broken and displaced grains, can be observed within the thrust zone west of this locality. They are best developed in quartzofeldspathic gneiss or schist of moderate mica content.

In a more comprehensive study of microstructures along the Chocolate Mountains and related thrusts, Simpson (1986) found addition evidence for northeastward overthrusting.

>>> Return to Stop 7, via the burro trail across the head of the canyon.

>>> A small arroyo drains south from the drainage divide that runs east from Stop 7. Walk southeast then south along the gentle slope west of this arroyo. Cross the arroyo near where it turns west-southwest, and continue south to the top of the low ridge. Stop 10 can be anywhere in the vicinity of the locality shown in Figure 1.

Stop 10: Orocopia Schist metagraywacke

The bulk of the Orocopia Schist is flaggy weathering quartzofeldspathic schist, with minor interlayered semipelitic schist. These schists are characterized by bluish-gray to black porphyroblasts of graphitic albite. Flysch-like compositional layering transposed from sedimentary bedding (Jacobson, 1983c; Haxel, 1977) is also characteristic, but is not as conspicuous here as it is in schist farther below the thrust or in schist exposed in polished outcrops in canyons or arroyos. Following Ehlig (1958), Orocopia quartzofeldspathic to semipelitic schists are called "grayschist".

Quartzofeldspathic Orocopia grayschist is composed essentially of albite, quartz, muscovite, biotite, microcline, and clinozoisite. Garnet is rare, except in the zone of coarse schist beneath the Chocolate Mountains thrust. The mineralogy of semipelitic schist is similar but more variable from place to place; chlorite is common, microcline is uncommon, garnet is present in some rocks, and albite and clinozoisite are absent in some rocks.

Major-element compositions of Orocopia grayschists are similar to graywackes rather than arenites, arkoses, or shales. Pb and Nd isotopic systematics, REE spectra, and major- and trace-element abundances indicate a predominant upper continental provenance (Silver and others, 1984; Bennett and DePaolo, 1982; Haxel and others, 1986). Geochemical data also suggest a subordinate component of island-arc or continental-arc detritus. Carbon content of the metagraywackes (0.05-0.8%) correlates with molecular $Al_2O_3/(Na_2O+K_2O)$, supporting the idea that the graphite originated as low-density organic debris concentrated in the more pelitic fraction of the sandstone.

Some layers of schist in this area have the coarse grain size typical of thrust-zone schist (Stop 6).

Foliation in the Orocopia Schist of this area dips moderately northward beneath the Chocolate Mountains thrust. Lineation plunges northeastward. Just south of here, the foliation and lineation are folded by antiforms and synforms of the Chocolate Mountains anticlinorium (Stop 14).

Polycrystalline aggregates, typically a centimeter or less in largest dimension, of bright-green fuchsite (Cr-bearing white mica) are widespread and rare to locally abundant in the grayschist. In some areas, including the eastern Gavilan Hills, Orocopia grayschist contains rare decimeter-size masses of talc-bearing actinolitite.

>>> Walk north and down from the ridge; recross the arroyo; look north or northwest. Find, and walk to, a group of closely spaced, resistant, dark-brown to

black weathering layers of metachert within the grayschist.

Stop 11: Orocopia metachert

These rocks contain about 85-90% SiO_2, 1-2% Al_2O_3, 7% Fe_2O_3*, and 1.4% MnO. They are composed essentially of quartz, spessartite, and magnetite, with minor hornblende, calcite, and apatite. Magnetite typically forms porphyroblasts several millimeters in diameter. Their ferromanganiferous character indicates that these rocks are metacherts rather than meta-arenites. Chondrite- or shale-normalized REE spectra have pronounced negative Ce anomalies, clearly indicating the marine origin of the chert (Shimizu and Masuda, 1977). Compared to Orocopia sandstones, the cherts are significantly depleted in Al, Ti, Zr, Hf, and Ta; and enriched in Fe, Mn, Ba, P, and Cu. Oxygen isotopic compositions are delta O18=16-26 permil. These and other geochemical data indicate that the Orocopia cherts are fundamentally biogenic deposits, with subordinate detrital and submarine hydrothermal components.

Some of the individual metachert layers grade into the enclosing metagraywacke; transitional rocks are micaceous metacherts. This indicates that the chert and sandstone were deposited together, not juxtaposed tectonically.

In some places, though not at this locality, metachert is accompanied by or grades into siliceous marble. Metachert is generally, and siliceous marble invariably, spatially associated with metabasalt. A thin layer of metabasalt crops out sporatically several meters to the south, between the metachert band and the arroyo. A larger body of metabasalt will be examined at Stop 12.

This group of metachert layers can be traced at least 200 m west, and a shorter distance east, from these outcrops.

>>> Follow the group of metachert layers west, parallel to the west-draining arroyo to the south. Cross a small south-draining arroyo. After walking west 100-150 m from Stop 11, turn north up a second and slightly larger south-draining arroyo. Walk north roughly 70 m, to a fork in the arroyo. Just north of this fork is an outcrop of metabasalt.

Stop 12: Orocopia metabasalt

Orocopia metabasalts are composed of hornblende; white, non-graphitic albite, porphyroblastic in some rocks; and epidote, typically with accessory chlorite and quartz. Many also have accessory garnet. Metabasalts within several hundred meters of the structurally overlying Chocolate Mountains thrust contain plagioclase in the range An22-34 rather than albite. Some of the metabasites contain a small amount of prograde metamorphic muscovite, suggesting affinity to high-pressure-intermediate metamorphic facies series (Miyashiro, 1973).

Orocopia metabasalts plot within or along MORB fields or trends on several widely used discrimination or variation diagrams, such as Th-Ta-Hf, Ti-Zr, Ti-V, Ti/Cr-Ni, and Ta-La. Absence of negative Nb-Ta anomalies on spidergrams suggests that the basalts are not island-arc related. REE spectra are virtually flat at 10-25 times chondritic. In this and several other aspects of their trace-element systematics, the Orocopia basalts are transitional between normal and enriched MORB (Dawson and Jacobson, 1986, Haxel and others, 1986).

Some metabasalts form layers, one-half to many meters thick and more-or-less laterally continuous; these may have been derived from submarine flows or tuffs. Other metabasalt bodies, such as the one at this Stop, are irregular or crudely lensoidal. Such bodies range from 10 to 300 m in largest exposed dimension. These might represent small sea-floor eruptions, intrusions, or olistoliths. To what extent these geometries are primary and to what extent they have been modified or created by deformation is generally unclear, or at least has not been elucidated.

Evidence as to the reason for the spatial association of metachert and siliceous marble with metabasalt is similarly obscured by deformation. Presumably the chert and limestone accumulated on submarine volcanic topographic highs, above the reach of most clastic sedimentation (Garrison, 1974). The basalts may also be responsible for the hydrothermal metalliferous component of the cherts and limestones.

Other bodies of metabasalt, metachert, or siliceous marble may be encountered during the remainder of the traverse.

Primary textural and mineralogic characteristics of the Orocopia protolith have been destroyed by metamorphism, so the nature and depositional environment of the protolith must be inferred chiefly from chemical compositions. Available geochemical data, in part summarized above, indicate that the protolith accumulated in a marine basin formed by oceanic spreading, not directly associated with subduction or an island arc, within or along a continental margin. Negative Ce-anomalies in Orocopia metachert and limestone suggest that this basin was more-or-less open to the ocean (Jenkyns and Winterer, 1982). Graywackes deposited in this basin were eroded from continental crust and possibly also from a continental-margin-arc terrane. Small amounts of siliceous and calcareous biogenic deposits, containing subordinate hydrothermal and detrital components, accumulated in localized environments largely shielded from clastic sedimentation.

>>> About 1/2 km southeast of the area of Stops 11 and 12 is a prominent low reddish-brown hill. Walk to this hill.

Stop 13: Serpentinite

This irregular body of serpentinite is semiconcordantly enclosed within but locally apparently intrudes the grayschist. In some places along the contact, the serpentinite has a sill-like relation to the moderately-dipping foliation of the schist; in other places the contact is subvertical and the serpentinite body appears pipe-like. Schist near the contact is apparently unaltered. A few meter-size inclusions of schist within the serpentinite are in structural continuity with the schist surrounding the body. The serpentinite is generally unfoliated. These relations indicate late-metamorphic emplacement of the serpentinite into its present position. The body could originally have been a serpentinite protrusion (Lockwood, 1972) or a peridotite or serpentinite olistolith. It could also conceivably have been a tectonic block transported along the Chocolate Mountains thrust, which is about 50-100 m structually above this locality (Fig. 2). However it got here, the presence of late Mesozoic serpentinite this far inland seems bizarre.

The serpentinite is composed largely of antigorite, with accessory magnetite and, in some rocks, carbonate. Bastites are visible in thin section. With increase in carbonate content, the serpentinite grades into less common serpentine-carbonate rock. The serpentinite is locally cut by veins, as much as 2 cm wide, of fiberous chrysotile.

>>> Climb to the top of the serpentinite hill. The highest point of the hill (peak 1315 (401 m)) is actually underlain by grayschist forming a reentrant on the south side of the serpentinite mass (Fig. 1). Stand here.

<u>Stop 14: Klippen of the Chocolate Mountains thrust; the Chocolate Mountains anticlinorium; regional overview</u>

<u>Klippen of the Chocolate Mountains thrust.</u> The large, blocky hill southeast of here, and the smaller peak to the south, are both capped by gneiss of the upper plate of the thrust. The approximate position of the thrust on the larger hill is apparent as a subhorizontal contact between darker, more rugged weathering gneiss above and lighter-colored, shiny, less resistant Orocopia Schist below.

<u>The Chocolate Mountains anticlinorium.</u> The two klippen south of here occupy the trough of a west-southwest trending synform that folds the foliation of the Orocopia Schist and also the overlying thrust. The crestal trace of an east-west trending antiform passes near the northern margin of the serpentinite body (Fig. 1). These small, open, discontinuous folds are third-order parts of the first-order Chocolate Mountains anticlinorium, which itself consists of several second-order antiformal segments. The Orocopia Schist of the Gavilan Hills marks a culmination along the crest of one of these second-order antiforms (Haxel and others, 1985). The area from this Stop north to the Gatuna fault, including Stops 3-12, is on the north limb of this second-order antiform.

<u>Regional overview.</u> Some geographic and geologic features visible from this vantage point, in order of azimuth clockwise from north:

000--Oligocene to early Miocene volcanic rocks. The stratigraphy established by Crowe (1973) and Dillon (1976) is visible here. The basal unit of the Tertiary section, depositionally overlying the Winterhaven Formation, consists of conglomerate, breccia, and sandstone. This basal unit is thin and discontinuous in this area. It is overlain by the Quechan Volcanic Formation, largely andesitic to rhyodacitic flows, which is in turn overlain by a complex unit of silicic air-fall and ash-flow tuffs, flows, and domes.

020--Colorado River; boundary between Imperial County, California to the west and La Paz and Yuma Counties, Arizona to the east.

060--Trigo Mountains, Arizona. Triassic and Jurassic plutonic rocks and Jurassic supracrustal rocks, at least some and possibly all of which belong to the upper plate of the Chocolate Mountains thrust (Haxel and others, 1985), overlain by Tertiary volcanic and sedimentary rocks. All of these are cut by low- to high-angle Tertiary extensional faults (Tosdal and Sherrod, 1985; Frost and Martin, 1982a)

080--20 km distant: Orocopia Schist in the southeastern Trigo Mountains, Arizona and the area east of Picacho, California (Haxel, 1977). 55 km distant, on the skyline: Castle Dome Peak, southern Castle Dome Mountains, Arizona. The next-to-easternmost exposure of Orocopia Schist is in the southeastern part of this range. The Castle Dome Pb district, largely hosted by Orocopia Schist, lies at the foot of Castle Dome Peak. Short segments of the Chocolate Mountains thrust overlying the Orocopia Schist are preserved in both of these areas.

120--Picacho Peak (590 m), the highest point of an extensive area of Oligocene and Miocene silicic and intermediate volcanic rocks (Crowe, 1973) and Oligocene to Holocene sedimentary rocks (Olmsted and other, 1973; Dillon, 1976).

195--Cargo Muchacho Mountains, composed largely of Middle and (or) Late Jurassic granitic rocks (Dillon, 1976).

225--Algodones Dunes. A branch of the San Andreas fault system lies beneath the sand dunes (Dillon, 1976).

300--Black Mountain and adjacent mesas, capped by 13-m.y.-old basalt (Crowe and others, 1979), stand high as a result of topographic inversion. The basalt apparently flowed southeastward along a pre-existing drainageway, and wegdes out at the small, low, black-topped hills about 1.5 km due west of Stop 14 (just off the southwest corner of Fig. 1). Conglomerate in which the basalt is intercalated contains dumortierite- and kyanite-bearing clasts derived from a terrane similar to the Cargo Muchacho Mountains (Dillon, 1976).

320--Peter Kane Mountain and Quartz Peak (660 m), made of Orocopia Schist intruded and thermally metamorphosed by Oligocene(?) epizonal granite and related porphyry (Haxel, 1977; Dillon, 1976). This exposure of Orocopia Schist represents a culmination along an antiform that is north of and subparallel to the antiform that passes through the Gavilan Hills (see above).

<u>Return hike</u>

The most straightforward route back to the vehicle parking locality: Walk west off the west end of the serpentinite hill, then northwest to a relatively large arroyo (about 650 m from Stop 14). Cross the arroyo, and several of its tributaries, and continue northwest toward a conspicuous gap or pass in the low hills. This pass is about 500 m from the arroyo and just west of the north-northwest trending fault shown in Figure 1. In passing, note large "quartz blowouts" in the Orocopia Schist. A well-defined burro trail leads from the west side of the pass north and down to Gavilan Wash. There is also a trail on the east side of the canyon.

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APPENDIX: CRITERIA FOR DISTINGUISHING OROCOPIA SCHIST AND UPPER-PLATE MYLONITIC ROCKS

This distinction typically is straightforward in thin section: plagioclase in Orocopia grayschist is generally poikiloblastic and commonly graphitic, whereas plagioclase in the upper-plate gneisses is neither. In the field, various combinations of the following criteria are useful. In many places, the first two criteria are of limited applicability within the thrust zone.

Attribute	Orocopia Schist	Mylonitic rocks derived from upper-plate gneiss
Grain size	Fine to medium	Medium to coarse
Foliation; fissility	Generally strong	Weak to strong
Plagioclase:		
Color	Commonly gray, bluish-gray, or black	White or light-gray
Habit	Porphyroblastic, in some rocks	Non-porphyroblastic
Hornblende:		
Abundance	Rare; only in metabasalt	Common to ubiquitous
Habit	Acicular, slender prisms; fine	Blocky or broadly prismatic; coarse
Compositional layering	Flysch-like, delicate	Gneissic, crude
Epidote--visible with hand lens?	Rarely	Not uncommonly
Graphite	Very common	Absent
Pegmatoid veins or segregations	Rare (but do occur locally)	Sparse to abundant

Some of these criteria are widely applicable to the Chocolate Mountains and related thrusts; others may be useful only in the Gavilan Hills and surrounding area.

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GNEISSIC HOST ROCKS TO GOLD MINERALIZATION

IN THE CARGO MUCHACHO MOUNTAINS,

SOUTHEASTERN CALIFORNIA

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INTRODUCTION AND LOCATION OF FIELD TRIP STOP

Drive to the Ogilby Road which is accessible either from Interstate 8 (20 km (12 miles) west of the thriving metropolitan area of Winterhaven, California) or from California 78 which connects Blythe and Brawley, California. From Interstate 8 drive north some 12 km (8 miles); from the junction of California 78 and the Ogilby Road drive south some 26 km (16 miles). The Cargo Muchacho Mountains are the isolated, desolate range to the east of the Ogilby Road. Park the vehicle(s) on the side of the Ogilby Road and walk eastward to the top of a spur off the westside of the central Cargo Muchacho Mountains where it comes close to the road (about 200 m distance) (Fig. 1). From the spur and by moving short distances north and south (few hundred meters), an overview of the lithologic units within the range is possible.

The canyon to the immediate north of the field trip stop is the location of the old townsite of Hedges and the various mines of the Tumco camp; the prospect pits on the slopes of the spur are included within the camp. The prominent canyon in the center of the range is formed by the American Girl Wash and is the site of the American Girl mine that has recently been explored by Newmont Mining Corporation. The larger workings at the mouth of the canyon and to the south are the Bluebird group kyanite and muscovite mines developed in the various facies of the Vitrefax Formation of Henshaw (1942). The next prominent canyon to the south is the location of the old Madre Padre mine where Newmont Mining Corporation also has explored and delineated a large, gneiss-hosted, disseminated gold deposit.

MAJOR LITHOLOGIC UNITS IN THE CARGO MUCHACHO MOUNTAINS

The Cargo Muchacho Mountains are composed of highly deformed Proterozoic(?), Paleozoic, and Mesozoic crystalline rocks (Fig. 1) that are inferred to be part of the upper-plate crystalline thrust sheet of the Chocolate Mountains thrust (Dillon, 1976). For the purposes of this field trip contribution, regional tectonics and structures within the range are largely ignored and only the major lithologic units spatially related to gold mineralization are briefly described. This description

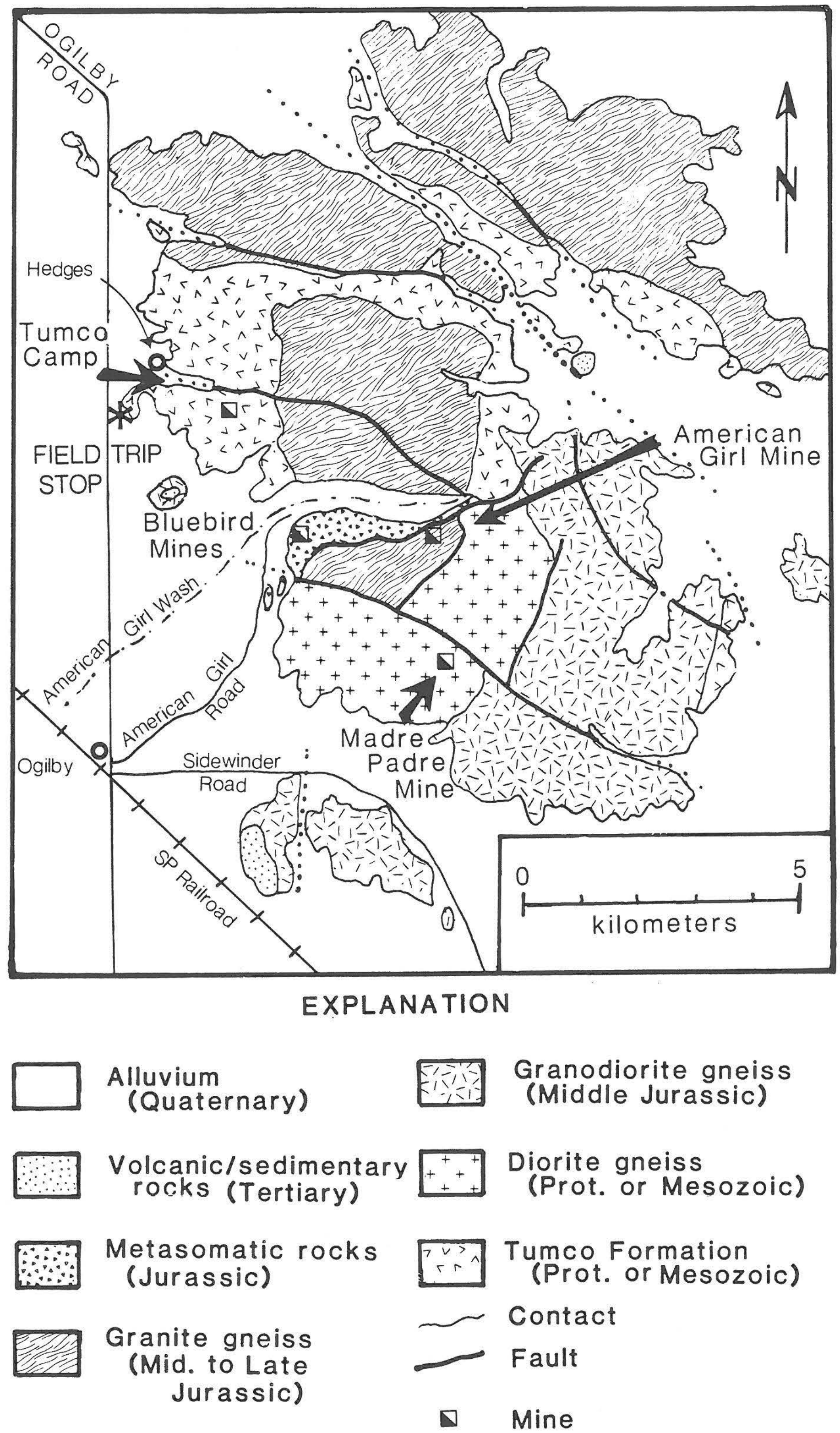

Figure 1. Generalized geologic map of the Cargo Muchacho Mountains, southeastern California, showing the major lithologic units and the past major gold producing mines and camps. Modified from Dillon (1976) and Morton (1977).

relies heavily on published information (Henshaw, 1942; Dillon, 1976) and is supplemented by my observations, biases, and conclusions. The rock units are described in order of decreasing age.

TUMCO FORMATION

The Tumco Formation is composed largely of biotite quartzofeldspathic gneiss (what you are standing on) with minor mafic schist. On the eastside of the range out of view from this stop are highly deformed quartzite, white marble, and wollastonite marble that were formerly included within the Tumco Formation by Dillon (1976) but subsequently recognized as probable upper Paleozoic cratonal rocks of North American affinity (R.E. Powell, 1985, personal communication). The Tumco Formation is the oldest unit in the range.

The protolith of the biotite quartzofeldspathic gneiss was considered by Henshaw (1942) to be a metamorphosed arkosite and the mafic schists to be meta-volcanic rocks. Dillon (1976) subsequently suggested that there was a significant component of volcanic rocks or detritus in the quartzo-feldspathic gneiss. The presence of relict bipyramidal, embayed quartz blastophenocrysts and abundant angular plagioclase and alkali feldspar blastophenocrysts(?) in the biotite quartzofeldspathic gneiss supports the inference of a largely volcanic or volcaniclastic origin of the protolith. In the Tumco mine area, there are locally abundant blastoclasts of augen gneiss and blastocrysts of large alkali feldspar in the gneiss; these blastoclasts are very similar to various Proterozoic augen gneiss exposed in the region, notably at Pilot Knob (located along the southside of Interstate 8, 10 km (7 miles) west of Winterhaven, California) and behind the McDonald's fast food eatery in Yuma, Arizona (at the intersection of Interstate 8 and US 95).

A Proterozoic age has generally been assumed for the Tumco Formation (Henshaw, 1942; Dillon, 1976; Morton, 1977). Tosdal and others (1985, 1986) propose a Mesozoic age for the quartzofeldspathic gneiss and suggest the formation is correlative with Early to Middle Jurassic rhyodacitic volcanic and derivative volcaniclastic rocks, hypabyssal porphyries, and related subvolcanic granite porphyry stocks which are widespread throughout the southwest. U-Pb geochronologic work currently in progress should resolve the age question.

DIORITE GNEISS

The diorite gneiss is an important lithologic unit exposed only in the vicinity of the Madre Padre deposit. The rock is well foliated and composed principally of hornblende, biotite, plagioclase, alkali feldspar, and quartz. Chemically, the rock is not a true diorite but has the silica composition of granodiorite (SiO_2 = 62.4%). In the Madre Padre deposit and also near the Bluebird mica mine, the diorite gneiss is intimately mixed with feldspathized biotite granite gneiss and is, itself, also locally feldspathized and altered (Dillon, 1976). The protolith age is unknown and was tentatively assigned a Proterozoic age by Dillon (1976), but could be and probably is of Mesozoic age.

JURASSIC ORTHOGNEISS

Two large meta-plutonic rock units, in addition to the Tumco Formation, compose the vast bulk of the Cargo Muchacho Mountains. These are, in decreasing age, hornblende-biotite granodiorite gneiss and biotite granite gneiss. Tosdal and other (1985, 1986) have included these rock within the regionally extensive Middle and Late Jurassic Kitt Peak-Trigo Peaks superunit, one of the important plutonic units of the Jurassic magmatic arc of the southwestern United States.

The hornblende-biotite granodiorite gneiss and the less common undeformed equivalents are characterized by conspicuous pinkish alkali feldspar blastophenocrysts and conspicuously large (few millimeter) euhedral sphene crystals. The well-foliated rocks compose the dark weathering skyline of the range to the south of the American Girl Wash. Phases of the orthogneiss, especially on the eastside of the range, are petrologically similar to the augen gneiss near the Picacho Mine. The plutonic protolith of the gneiss extensively intruded the Tumco Formation prior to the regional metamorphism that affects the entire range. A single concordant U-Pb zircon age of 173 m.y. indicates the protolith granodiorite is of Middle Jurassic age (Chen, in Dillon, 1976).

The leucocratic biotite granite gneiss composes the bulk of the northern half of the range and is characterized by its white weathering and low biotite content (color index < 5). The protolith granite intruded the older lithologic units and their tectonite fabrics, but is itself also strongly foliated. Available U-Pb zircon dates are all slightly discordant with dates between 130 and 150 m.y. (Saleeby, in Dillon, 1976; Tosdal, unpublished data); the discordancy is due to Pb loss. The radiogenic 207Pb/206Pb dates range from 161 to 169 m.y and are interpreted to indicate a Late Jurassic age of about 165 m.y. for the protolith granite. Although the U-Pb isotopic data is discordant and insufficient data is available to define a unique concordia intercept age, it does not allow a Late Cretaceous or Early Tertiary age as inferred by Keith (1984). The gneiss is spatially related to all of the past major gold producing districts as well as Newmont Mining Corporation's Madre Padre deposit.

APLITE AND PEGMATITE

Biotite leucogranite, aplite, and pegmatite, some of which contain garnet and muscovite, extensively intrude all of the rock units in the range as single dikes or dike swarms. The dikes are apparently related to the biotite granite gneiss (Dillon, 1976). However, the possibility that there is more than one generation of dikes can not at this time be discounted.

Many of the dikes are deformed and contain a tectonite fabric parallel to the regional fabric in the country rock; others sharply intrude the country rock and in a few cases fold the regional fabric. Still other dikes can be followed from segments that sharply intrude and fold the regional fabric to segments in the same dike which are slightly foliated and boudinaged. These mutually conflicting relationships between the dikes and the regional fabric implies that the dikes were late syn- to post-kinematic intrusions. Some of the dikes can be examined at this stop where they intrude the quartzofeldspathic gneiss of the Tumco Formation.

The dikes are spatially related to the margins of the biotite granite gneiss. Away from the granite gneiss, the dikes are relatively sparse in number. As the main mass of the biotite granite gneiss is approached, the abundance and thickness of the individual dikes increases progressively. Prior to the contact with the granite gneiss, the dikes are so abundant that the country rock forms only thin screens between the dikes. Some aplite and pegmatite dikes intruded the outer parts of the granite gneiss, but are conspicuously absent from the interior parts of the pluton. This spatial relationship of the dikes to margins of the granite gneiss implies, but does not prove, that the aplite and pegmatite dikes are genetically related to the biotite granite gneiss. A late Middle or Late Jurassic(?) age may be tentatively assigned to the dikes.

If the dikes should prove to be the same age as the granite gneiss (late Middle or Late Jurassic) and because they are late syn- to post-kinematic intrusions, the regional metamorphism in the range should be of Middle or, at the youngest, earliest Late Jurassic age. This age is too old for the fabric to be related to the movement along the Late Cretaceous Chocolate Mountains thrust as proposed by Dillon (1976) (see Haxel and Tosdal, 1986, for a summary of recently available age constraints for the Chocolate Mountains thrust). The late Middle to earliest Late Jurassic age for the regional metamorphism is similar but slightly older than and perhaps tectonically equivalent to a regional metamorphism identified in several ranges to the north in the vicinity of Quartzsite, Arizona, and Blythe, California (Tosdal, 1986; Tosdal and others, 1986).

A Late Jurassic age for the aplite and pegmatite and the regional metamorphism is as yet unproven, although the evidence summarized here is strongly suggestive. However until the critical U-Pb isotopic data is available, other age assignment to the dikes and to the regional metamorphism must also be considered. First, Keith (1984, Keith and Wilt, 1985) assign an Early Tertiary age to the aplite and pegmatite dikes and granite gneiss, in particular to those which contain garnet and white mica. They base their age assignment on the chemical composition and mineralogy of the rocks and the apparent similarity of their chemistry to the early Tertiary peraluminous granites to the east and northeast in Arizona (Keith and others, 1980; Keith and Reynolds, 1980; Wright and Haxel, 1982). Second, some or all of the dikes could be related to Late Cretaceous plutons now exposed in the San Gabriel Mountains, southern California (Carter and Silver, 1972; Walker and May, 1986), that have been offset from a geographic position contiguous with the Chocolate and Cargo Muchacho Mountains by dextral strike-slip motion along faults of the Neogene San Andreas fault system (Crowell, 1981; Powell, 1981). These possible ages for the aplite and pegmatite dikes are clearly testable by the application of U-Pb isotopic geochronology.

METASOMATIC ROCKS

Aluminous gneissic and granofelsic rocks of metasomatic origin were derived from the quartzo-feldspathic rocks of the Tumco Formation and the Late Jurassic(?) biotite granite (Dillon, 1976). Those metasomatic rocks derived from the Tumco Formation were previously known as the Vitrefax Formation (Henshaw, 1942), a name which is still used to refer to the rocks informally. Formation of the rocks involved extensive hydrogen metasomatism and leaching of mobile elements during fluid flow under high fluid to rock ratios (Wise, 1975). The metasomatic rocks are considered to have formed synchronous with intrusion of the biotite granite gneiss (Dillon, 1976) and may also have been syn-metamorphic. The metasomatic rocks are common in the central part of the range along the southern margin of the biotite granite gneiss and are spatially related to the past richest gold producing districts (Henshaw, 1942; Sampson and Tucker, 1942; Dillon, 1976), an association also noted on a regional scale (Tosdal and others, 1985).

Metasomatism of the quartozfeldspathic gneiss of the Tumco Formation produced rocks which grade from unaltered gneiss to feldspathized quartzofeldspathic gneiss to muscovite-quartz schist to muscovite-kyanite-quartz granofels and gneiss to kyanite-bearing quartzite in the most highly metasomatized rocks. Accessory minerals in these rocks include biotite, tourmaline, magnetite, ilmenite, pyrite, rutile, andalusite, lazulite, staurolite and dumortierite. In the biotite granite gneiss, the metasomatic alteration of the rock produced feldspathized biotite granite gneiss and finally biotite gneiss in the most metasomatized state. The biotite gneiss is petrologically and chemically similar to the diorite gneiss described previously. Veinlets of pyrophyllite, which is a retrograde mineral replacing kyanite and andalusite, and quartz + tourmaline + pyrite locally cut the higher grade metasomatic rocks (Dillon, 1976).

In the vicinity of the Bluebird mica mine, a nearly complete transition from non-metasomatic gneiss of both types to thoroughly altered metasomatic gneiss and granofels can be easily seen. (The Bluebird mine can be reach via the American Girl Road which intersects the Ogilby Road near the railroad crossing). Some of the transitions between the different facies of the metasomatic gneiss are well exposed, although these exposures are small. Please do not remove these small exposures; samples of the major rock types are abundant and easy to sample.

Near the Ogilby Road and the parking area a small exposure of the metasomatic rocks is present. It is located just north of the northern finger at the end of the spur you have climbed. The exposure is within a few tens of meters from the Ogilby road adjacent to a small wash at the edge of the undissected fan. The metasomatic rocks here are not as spectacular as those near the Bluebird mines, but nevertheless are still mineralogically interesting.

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DAY 2

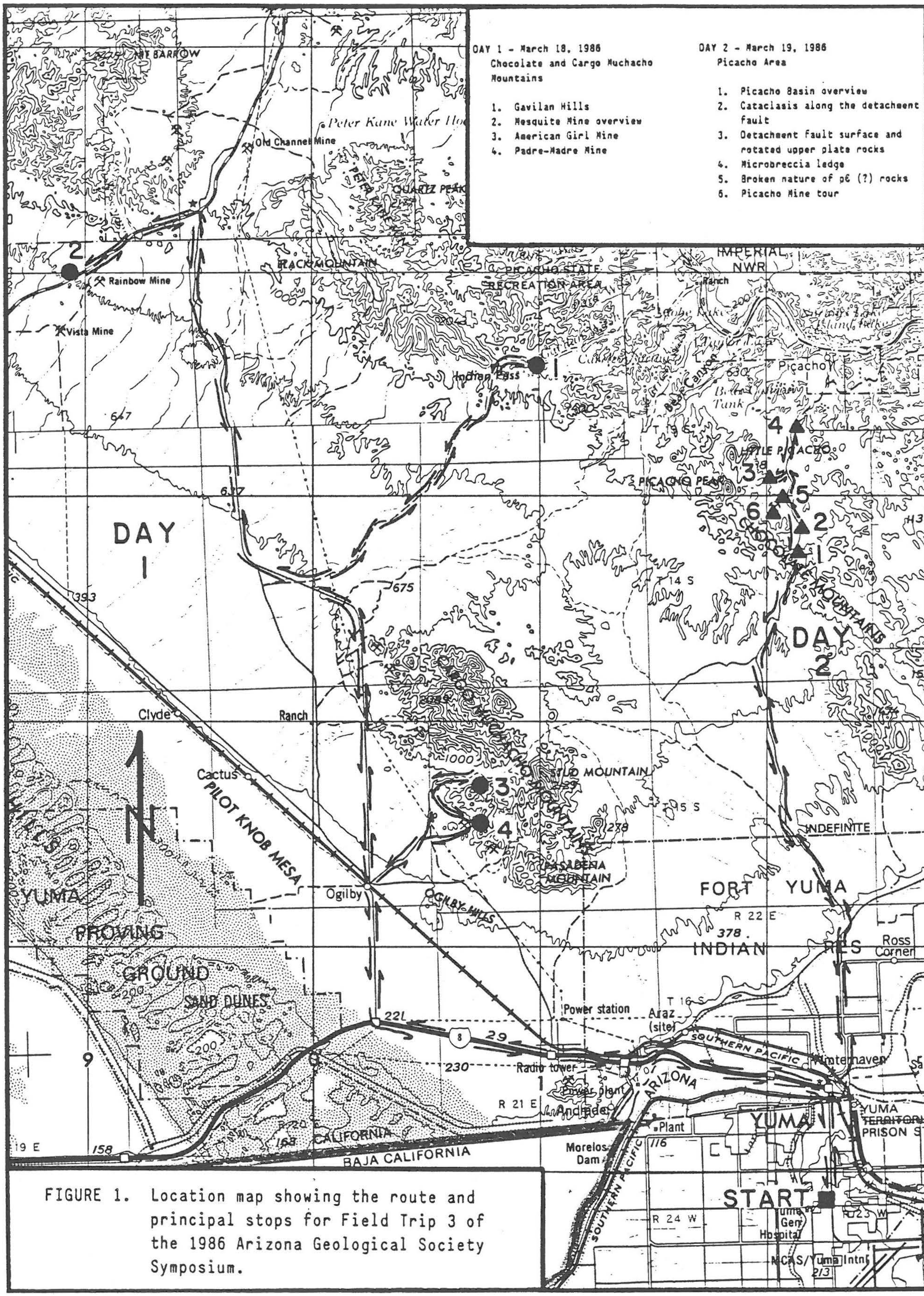

FIGURE 1. Location map showing the route and principal stops for Field Trip 3 of the 1986 Arizona Geological Society Symposium.

SECOND DAY ROAD LOG

WEDNESDAY, MARCH 19, 1986

YUMA - PICACHO MINE

Assembly point: Stardust Motel
Distance: 45 miles
Stops: 6

The purpose of today's trip is to examine the overall structural setting in the Picacho area and to relate this to the mineralization, alteration, and structural style at Chemgold Inc.'s Picacho mine. This will be accomplished through several short traverses in the Picacho basin and then a tour of the Picacho mine. The trip today will be led by Peter A. Drobeck (Western States Minerals Corp.) and Gail S. Liebler (University of Arizona).

0.0 Parking lot of Stardust Motel. Turn left and proceed north on 4th Avenue. 3.0

3.0 Crossing Colorado River, enter California and the Quechan Indian Reservation. 0.2

3.2 Continue straight ahead toward Winterhaven instead of turning onto I-8. 0.3

3.5 Turn right on County Road S24 to Picacho State Recreation Area. 0.25

3.75 Cross Yuma Main Canal. 0.05

3.8 Turn left and proceed through railroad underpass. 0.3

4.1 Bear left. 0.3

4.4 Picacho Peak at 11:00. 0.5

4.9 Intensive agriculture occurs along the Colorado River flood plain. Since the Reclamation Act of 1902 which provided water for substantial agricultural developments, it has been Yuma's primary industry. 1.9

6.8 Low hills on the skyline from 12:00-2:00 are the Picacho area which form the southeasternmost part of the Chocolate Mountains.

GEOLOGY OF THE PICACHO AREA

The pre-Tertiary geologic setting of the Picacho area is equivalent to that discussed in the northern Chocolate Mountains and in the Cargo Muchacho Mountains; however, the Tertiary is characterized by an abundance of volcanic and sedimentary rocks. Since the pre-Tertiary rocks were discussed in the first day's road log, the reader is referred to that section.

The following discussion of the Tertiary rocks in the Picacho area is taken from Crowe (1978). A complex sequence of Oligocene age volcanic and volcaniclastic rocks forms a major volcanic center in the Picacho area. The volcanic rocks define a slightly bimodal, calc-alkalic suite formed largely of silicic lavas and subordinate andesites.

Basal volcanic rocks consist of lava flows and flow breccias of trachybasalt, pyroxene rhyodacite, and pyroxene dacite. These rocks form the 32 m.y. old Quechan volcanic rocks. They locally overlie fanglomerates and rest unconformably on pre-Tertiary basement rocks. The Quechan volcanic rocks are overlain and locally intruded by rhyodacitic to rhyolitic volcanic rocks called the rhyodacite of Little Picacho Peak.

These earlier rocks are overlain by a rhyolite ash-flow tuff (26 m.y. old) which forms a major ash-flow sheet. This unit, the ignimbrite of Ferguson Wash, has a minimum volume of 40 cubic kilometers but is not associated with any subsidence features. A thick section of dacite lava flows and breccias, the dacite of Picacho Peak, overlies the ignimbrite of Ferguson Wash.

The youngest of the volcanic units consists of lava flows and flow breccias of pyroxene andesite. This unit has been dated at 25 m.y. The volcanic sequence is overlain by the conglomerate of Bear Canyon (the unit which caps Picacho Peak) and older alluvium.

Structurally the Picacho area is similar to the other areas discussed with good exposures of the Chocolate Mountains thrust along the Colorado River. The presence of numerous marker units in the Tertiary section allows for better definition of younger faulting than elsewhere. The volcanic rocks have been intensely broken by northwest-trending normal faults and the units have been rotated 20° to 45° to the southwest along these faults onto the Chocolate Mountains detachment fault (Drobeck et al., this volume).

Begin gravel road. 1.1

7.9 Begin ascent onto pediment capped by Colorado River gravels. 0.1

8.0 All American Canal. 0.3

8.3 Turn left and cross the canal. The low area is a flume to allow natural drainage across the canal.

Climbing through a thick section of older alluvium. 1.2

9.5 Road to Yuma dump, continue ahead. 0.4

9.9 Cargo Muchacho Mountains 9:00-11:00. 1.5

11.4 Cross under power line. 0.8

12.2 Picacho Peak is the prominent landmark at 12:00. 4.1

16.3 Road bears hard right. 1.1

17.4 Picacho State Monument sign, 14 miles ahead. 0.1

17.5 Hard right, begin descent into broad wash. 0.4

17.9 Enter wash and turn left. Note gently tilted gravels and siltstones. 0.4

18.3 Pebble Mountain, on the right, is capped by 25 m.y. old pyroxene andesite. 0.1

18.4 Look to the left across and into wash. Note thin layer of Colorado River gravels covering older, tilted sediments. 0.9

19.3 Outcrops of Tertiary volcanic rocks. Outcrops here are of the dacite of Picacho Peak. 0.6

19.9 Stop 1. Park vehicles on right. Climb small hill for an overview of Picacho basin. Rock types, stratigraphy, structure, and geologic history will be discussed. 0.7

20.6 Stop 2. Park vehicles off main road. This stop will be a short traverse to examine the Chocolate Mountains detachment fault and will illustrate the differences in behavior of two different rock types along the detachment fault. On a traverse along the wash to the northeast we will examine the Marcus Wash Granite in the detachment zone. Here the Marcus Wash is intensely shattered and cataclasized.

On a traverse up the wash to the west we will examine the less intense cataclasis in the Precambrian(?) gneisses in the detachment fault zone. This stop is described in detail in the paper by Drobeck et al. (this volume). 0.4

21.0 Dumps of Picacho mine barely visible at 11:00. 0.35

21.35 Good view of Picacho Peak and Picacho mine leach dumps at 12:00. 0.15

21.5 Road to left goes to the Picacho mine, proceed to the right. We will come back for a tour of the mine. 0.4

21.9 Historical marker on the right describing the Picacho placers. Opened by placer miners after 1852, the gold mines expanded into hard rock quarrying by 1872. Picacho employed 700 miners at its peak from 1895 to 1900. Mill accidents, low ore quality, and the loss of cheap river transport with the building of Laguna Dam led to numerous periods of inactivity. With ores far from worked out, the Picacho mines, using modern techniques, again resumed operations in 1984. California Registered Historical Landmark No. 193. 0.4

22.3 Note thin (6 to 10 feet) veneer of gravels on bedrock at left. 0.15

22.45 Intersection of Little Picacho Wash and Burro Wash. Turn left up Little Picacho Wash. Note numerous high angle faults cutting contorted Winterhaven Formation. 0.15

22.6 Stop 3. Park vehicles where jeep trail enters wash from both sides. We will traverse through the Winterhaven Formation to examine the rotation of upper plate rocks onto the detachment fault and to examine the detachment fault zone (Drobeck et al., this volume).

Turn around and return to the main road. 0.2

22.8 Picacho Road, turn left and proceed down the wash. On the left at the junction of the two washes, a high angle fault displaces Winterhaven Formation (on the west) against red Quechan volcanic rocks (on the east). 0.1

22.9 Now travelling on the bed of the Picacho and Colorado River Railroad. This was a 5-mile line built to connect the mines near Picacho Peak with the town of Picacho on the Colorado River. 1.0

23.9 Wash enters from left. Dumps and remains of buildings from Georgia gold mine. Continue down the wash. 0.1

24.0 Stop 4. Park vehicles to the right. A short traverse will take us to exposures of a cataclasite ledge -- a classic microbreccia ledge -- on the Chocolate Mountains detachment fault. Samples of the microbreccia assay greater than 1 ppm gold (Drobeck et al., this volume).

Turn around and drive back to the Picacho mine turnoff. 2.2

26.2 Turn right toward the Picacho mine. 0.05

26.25 Cross wash. Stop 5. We will take a short traverse down the wash to examine the broken nature and alteration of the Precambrian(?) gneisses. We will also compare the similarity of structural style here with what we have already seen and compare it with what we will see in the pit. 0.15

26.4 Gate to the Picacho mine. Stop 6. We will meet Tom Wood, General Manager of the Picacho mine for a tour. Pete Drobeck and Gail Liebler will lead the discussions. Stops in the mine will include the San George area to look at the silicified character of the detachment fault, the Apache pit to examine the bottom of the ore zone, and the Dulcina pit.

THE PICACHO MINE

The Picacho mine is a low grade, open pit, heap leach gold mine that is operated by Chemgold, Inc., a wholly owned subsidiary of Glamis Gold, Ltd. Glamis Gold reported that their gold production from Picacho for the fiscal year ending June 30, 1985, was 24,776 ounces. They recorded net earnings of $2.2 million with a production cost of $125.00 per ounce of gold. Reserves at Picacho are 9.7 million tons grading 0.044 oz/ton gold. Current production is from the Apache and Dulcina orebodies.

As with the mineralization at Mesquite and in the Cargo Muchacho Mountains, there is some debate regarding the genesis of mineralization at Picacho. The three most often discussed ideas are: 1) mineralization related to Laramide age peraluminous-calcic pegmatite and aplite dikes; 2) ground preparation due to thrusting--mineralization may be younger; and 3) mineralization related to detachment faulting (Van Nort and Harris, 1984; Drobeck et al., this volume).

The leaders of this portion of the trip will present data in support of the detachment fault model.

THE PICACHO MINE: A GOLD MINERALIZED DETACHMENT IN SOUTHEASTERN CALIFORNIA

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ABSTRACT

The Picacho gold mine, which is an important gold producer in southeasternmost California, is operated by Chemgold, Inc. Ore is mined by open pit with a low stripping ratio and gold is recovered by inexpensive heap leaching.

The region surrounding Picacho has undergone three major structural disturbances. In late Cretaceous time a series of Precambrian(?) gneisses and schists were thrust over Jurassic Orocopia Schist along the mylonitic Chocolate Mountains thrust. In Oligocene time extension of the crust culminated in producing the Chocolate Mountains detachment fault (CMDF). Textures and mineralogy of the fault zone, as well as reconstructed stratigraphy, indicate the detachment fault formed as shallowly as one kilometer in the vicinity of the mine. Seismic studies by CALCRUST indicate the fault extends to midcrustal levels further north. The upper plate of the shallowly-dipping CMDF includes Jurassic(?) Winterhaven Formation and Oligocene fanglomerates and volcanic rocks. The lower plate includes Orocopia Schist, Precambrian(?) metamorphic rocks, and Cretaceous Marcus Wash Granite. The latest major structural event was an intense episode of normal faulting which dissected the thrust and detachment fault. It is presently unclear if this late episode is related to a younger, much deeper detachment fault, Basin and Range faulting, or motion on the San Andreas Fault.

The four orebodies which comprise the Picacho mine are localized along the CMDF zone of cataclasis. No relationship between ore and the thrust fault was established. The hanging wall to all of the hypogene ore is barren Oligocene Quechan volcanics. The uppermost surface of the CMDF usually shows an abrupt termination of gold mineralization. The footwall is a gradational and erratic feature, suggesting it was the feeder zone for the ore. Ore is comprised of cataclasized Precambrian(?) metamorphic rocks and Cretaceous Marcus Wash Granite which have been mineralized with pyrite, hematite, quartz, and gold. Felsic gneisses and Marcus Wash Granite host the best grades of ore because of their tendency to shatter and take up a disproportionately large share of extensional strain by cataclasis. The most cataclasized rocks were most porous to mineralizing solutions and show the best gold grades. Biotite gneisses and schists are commonly less cataclasized and mineralized. A large share of the hypogene ore was eroded from post-ore horsts and preserved as talus breccias.

Preliminary fluid inclusion work indicates homogenization temperatures in synmineralization quartz of 201° to 226° C with salinities of 0.5 to 0.7 weight percent NaCl equivalent. Trace element geochemical studies show anomalous arsenic and antimony associated with the ore and dispersed beyond. These temperatures and trace element anomalies are typical of epithermal deposits.

Porosity and permeability developed by brecciation within the CMDF zone provided access for mineralizing fluid. Our observations suggest that the Picacho gold mineralization formed when rising epithermal fluids, carrying gold in bisulfide complexes, intersected the CMDF zone. The fault zone probably was a fresh water aquifer until these epithermal fluids reached it. When these fresh waters oxidized the epithermal fluids, the gold was precipitated with and onto pyrite grains. The association of gold with primary pyrite and hematite indicates varying conditions of oxidation as these fluids mixed. The structural aspects of our explanation are applicable to many gold, silver, manganese, and copper deposits in the southwestern USA, but the geochemical mechanism may be unique to Picacho or southeastern California.

Leave the Picacho mine and retrace the route to Yuma. 18.3

44.7 Turn left (east) on I-8 and return to Tucson for registration, the welcome party, and the poster session.

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FIELD GUIDE TO THE PICACHO MINE AND VICINITY, SOUTHEASTERNMOST CALIFORNIA

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INTRODUCTION

This field trip will examine the character of detachment faulting in the Picacho Mine vicinity as well as the character of mineralization and structure in the Picacho Mine. The character of the Chocolate Mountains Detachment Fault (CMDF) is unique to the SW U.S.A. and is also quite variable. Work by the authors suggests the variability is due to the shallow level of faulting (on the order of 1 km.) (Drobeck and others, 1986). The gold mineralization at the Picacho Mine appears very similar to some outcroppings of the CMDF and occurs at the same contact. This field association, and the occurrence of the gold in detachment-related cataclasite matrix indicates that the gold mineralization occurred during and after detachment faulting.

ROAD LOG AND FIELD DESCRIPTIONS

Mileage	
00.0	Parking lot of Stardust Motel. Proceed north on 4th Avenue.
03.0	Cross Colorado River and enter California. The isolated mountain at 9:00 is Pilot Knob where L.T. Silver determined the age of an augen gneiss (which intrudes banded and laminated gneisses) to be 1700 mya (Dillon, 1975). The age of other gneissic rocks in SE California and SW Arizona is uncertain as indicated by Jurassic ages of similar rocks (Tosdal and others, 1985).
03.5	Turn onto County Road S24 to Picacho Recreational area.
03.7	Turn left across Yuma Main Canal.
07.9	Pavement changes to dirt road. Note the nearly flat-lying flows capping the mesas at 1:00 to 2:00. These flows were described by Crowe (1978, 1973) as pyroxene andesites for which he cited a whole rock K-Ar age determination by Olmsted and others (1973) of 25.1 $\pm$ 1.6 mya. These nearly flat-lying flows have not been rotated by detachment-related normal faulting as most of the other volcanics in the region have been. Thus, their extrusion dates the cessation of detachment faulting in the region. It should be noted that one of the main volcanic tuffs in the region, the white-colored tuff of Ferguson Wash, has been tilted 25° to 45° southwestward by numerous normal faults in the upper plate of the Chocolate Mountains Detachment Fault (CMDF). This tuff was also cited by Olmsted and others (1973) as being radiometrically dated at 25.9

$\pm$ .9 mya (biotite) and 26.2 $\pm$ 1.6 mya (sanidine). Hence, the radiometric ages indicate the tuff and the capping andesites are nearly synchronous, suggesting that detachment faulting came to an exceptionally abrupt end at approximately 25 mya. An alternative explanation is that the 25.1 $\pm$ 1.6 mya whole rock age of the capping flows is anomalously old. Pyroxenes in the andesite could easily have inherited Ar^{40} from older surrounding rocks before eruption of the volcanic flows, and thereafter result in anomalously old whole rock age determinations (Martin-Frost, pers. commun., 1986).

More mafic augite-olivine basalt forms flat mesas throughout much of the region such as Black Mountain (approximately 12 miles WNW of the Picacho area) where Krummenacher obtained a plagioclase K-Ar age of 13.1 $\pm$ 2.5 mya (Crowe, 1978). This basalt is typical of post-detachment flows in the southern Cordilleran and reflects the change to fundamentally basaltic magmatism as seen in much of the Basin and Range (Suneson, 1980).

08.3 Turn left over All American Canal.

11.4 Cross under new powerline. Where the road splits, keep to the right, the Cargo Muchacho Mountains loom at 9:00. From this vantage point we see the east flank of the range which, in contrast to the west flank, is not known to be mineralized.

At 12:00 note the prominent Picacho Peak comprised of an eroded dacite plug overlain by late Tertiary (Crowe, 1973) conglomeratic gravels. The topographic difference between the gravels on the peak and similar gravels in the surrounding basins is at least 500 feet, indicating some sizeable offsets by late Tertiary faulting. We have not studied these gravels, but Crowe (1973) indicated them to be generally flat-lying "although locally it is steeply tilted and folded". Crowe (1973) also indicated that the "Conglomerate rests with buttress unconformity upon the Picacho "ignimbrites", Picacho Peak dacite, and pre-Cenozoic basement rocks." We have not studied these relationships.

The white claimposts along the road are part of a large land position controlled by Gold Fields Mining Corp., who are actively exploring much of this region.

17.9 Road switches back in wash. On the southeast side of the road a 20' cliff of young gravels is cut by N5^{0}E to N15^{o}E faults. These young faults might be genetically related to the San Andreas Fault zone which is approximately 20-25 miles to the west. We presently do not understand how much of the deformation in the Picacho vicinity is related to the San Andreas. Young WNW and ENE trending faults are numerous in the region and many have been found to have strike-slip striae on fault surfaces. However, other faults with the same trend have been found with dip slip striae.

19.3 Note outcrops of the dacite of Picacho Peak, the uppermost tilted unit of the volcanic package.

19.9 STOP 1. Overview Stop

Pull over onto a side road to the right and park. Then walk uphill where we will discuss the regional stratigraphy and structure. To the north of this hill is the Picacho Mine, which we may be able to hear working.

The stratigraphy of the Picacho area can be easily divided into three structural packages (FIGURE 1):

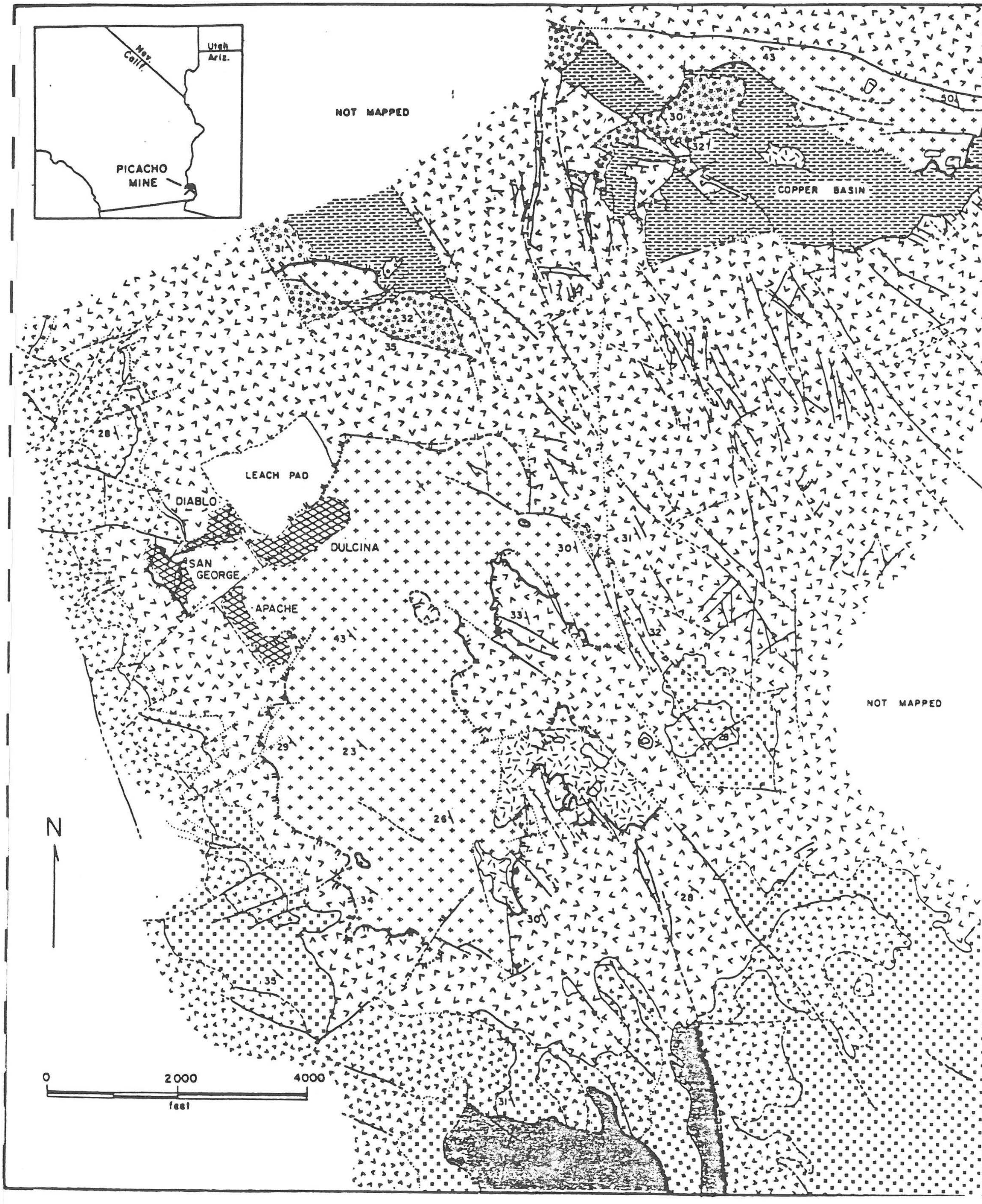
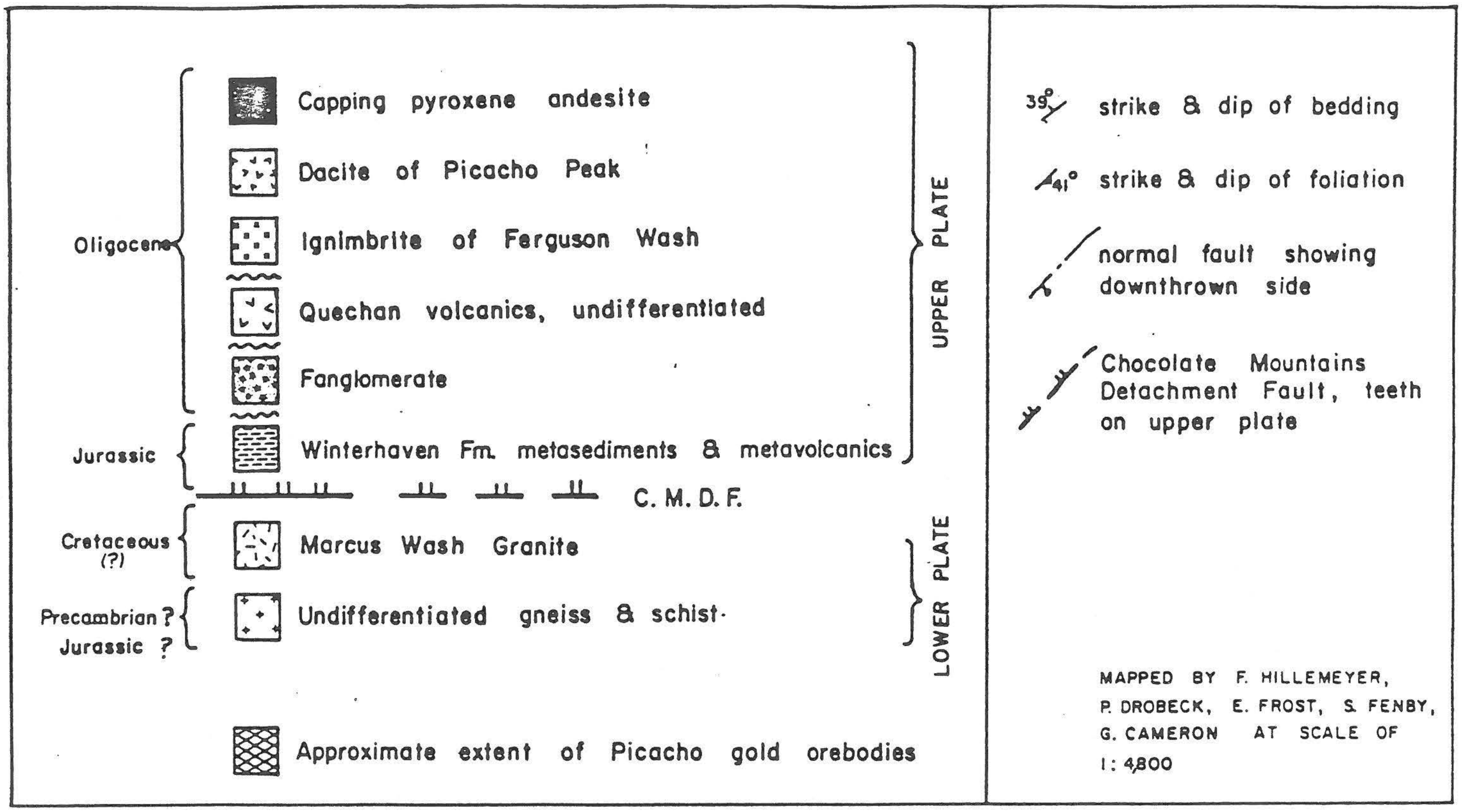


FIGURE 1. Geologic map of the Picacho Mine vicinity from Drobeck and others (1986).



Explanation for FIGURE 1.

A. The structurally lowest rock unit is the Jurassic (?) Orocopia Schist (Haxel and Dillon, 1978, Haxel, 1977) which forms the lower plate of the Late Cretaceous Chocolate Mountains Thrust. Neither the thrust nor the schist have been observed in the Picacho Mine. However, the thrust has been mapped by Haxel (1977) on a hill approximately 4 miles north of here. From this vantage point we can see a large mass of the schist outcropping in the far distance in the Trigo Mountains at 2:00.

B. Above the thrust Haxel (1977), Haxel and Dillon (1978), Dillon (1975) and Harris and Van Nort (1985) mapped a series of gneisses and schists tentatively termed Precambrian. More recent work by Tosdal and others (1985) and Tosdal (1986) have indicated that these rocks are actually Jurassic. These gneisses form the greenish-brown domal hill from 10:30 to 12:00. On this hill the foliation dips uniformly southwest.

The Marcus Wash Granite (Haxel, 1977) is included in the same structural plate as the gneisses but it may cut the Orocopia Schist at levels we don't see in this vicinity. It has been observed being intruded along the Chocolote Mountains Thrust and has been tentatively assigned a late Cretaceous age (Haxel and others, 1985). This granite can be seen on the whitish hill in the foreground at 12:00 where it is intensely brecciated. Our mapping did not extend quite this far south but indicates that the regional detachment fault projects just above this outcrop and that it caused the brecciation.

C. The Chocolate Mountains Detachment Fault separates the gneisses and Marcus Wash Granite from an upper plate assemblage (rare slices of the gneiss have been noted in the upper plate regionally). The oldest rocks in this assemblage are the Winterhaven Formation, which has been described by Haxel and others (1986) as Jurassic in age. It is comprised of sedimentary and volcanic rocks metamorphosed to phyllites.

The Winterhaven Formation is unconformably overlain by a series of fanglomerates and predominantly calc-alkalic volcanics ranging from basalt through rhyolite (Crowe, 1978; FIGURE 1). From our vantage point we cannot see the two lowermost units but the main volcanic sequence is spectacularly exhibited on on the high ridges from 6:00 to 12:00. The lowermost volcanic unit we can see is the Quechan Volcanics which have been dated as 22.9 $\pm$ .6 mya (whole rock) and 21.3 $\pm$ .6 mya (plagioclase) (reported in Crowe, 1973) but also as 31.8 $\pm$ 3.2 mya (plagioclase) as reported by Crowe (1978). This unit usually forms slopes and rolling hills in the region because it is soft, crumbly flows, flow breccias, and agglomerates. The prominant ridges we see to the west have Quechan Volcanics at their base. Their composition ranges from trachybasalt to pyroxene rhyodacite.

The ignimbrite of Ferguson Wash (Crowe, 1978) lies stratigraphically above the Quechan Volcanics and forms the prominent white marker horizon along the cliffs to the west and elsewhere in the region. Its thickness ranges from a few feet to 1000 feet, indicating it was erupted over a rough topography. Olmsted and others (1973) indicated age determinations on this unit of 25.9 $\pm$ 0.9 mya (biotite) and 26.2 $\pm$ 1.6 mya (sanidine). Crowe (1978) indicated the tuff appeared to be one cooling unit with a volume on the order of 40 km^3, and was baffled to find no associated collapse feature.

Fieldwork has shown that this tuff generally dips only 20°-40° whereas the underlying Quechan Volcanics have dips from 20°-65°. We believe this tilting to be caused by detachment faulting, hence, it seems apparent that the Quechan Volcanics had been rotated 10°-30° at the time of eruption (analogous to the setting of the Gene Canyon - Copper Basin Formations in the Whipple Mountains as described by Davis and others, 1980. Hence, it appears detachment faulting was progressing at the time of eruption. Whether the active detachment faulting allowed for eruption of the tuff by venting along numerous faults and feeders, or if there was a cauldron in the region which is no longer recognizable due to the subsequent intense deformation is not known. It is interesting to note that there are numerous massive ash flow tuffs in SW Arizona and SE California, but associated cauldrons have not been recognized.

This ignimbrite is overlain by the Picacho Peak dacite flow-dome complex (Crowe, 1978,1973). Flows and flow breccias of this resistant formation cap the prominent ridges to the west. Crowe (1978) noted this unit underlies the ignimbrite of Ferguson Wash .6 miles north of

Picacho Peak. Picacho Peak, at 10:00, is a plug of similar dacite covered by the late Tertiary Bear Canyon Conglomerate (Crowe, 1977, Olmsted and others, 1973).

Note that the volcanic rocks within our vista are all strongly tilted. NW-trending normal faults are the prominent structural trend in the region, generally perpendicular to dips of the volcanics. A major NW-trending normal fault has been inferred on the west side of the ridge we see and appears to have caused rotation of the beds. This structural style is typical of the upper plate of detachment faults throughout the southwest.

An equally prominent structural grain is the ENE faulting which has chopped up the ridge to our west. The faults have variable offsets of a few tens of feet up to 700 feet of stratigraphic separation. Few striae have been observed on this ridge, but those observed indicated normal movement. However, faults with similar trends have been found 2 to 3 miles north of us with horizontal striae. The faults are at least partially post-detachment faulting and post-ore. They may have initiated as tear faults during detachment faulting, but then later accomodated San Andreas-related deformation.

The domal hill of gneiss to the NNW has Quechan Volcanics surrounding it on all sides. This dome shaped structural window of gneiss is elongated in a NNW direction (8000' NNW x 3000-5500' ENE) mimicing the structural grain of detachment-age faulting. The contact between the gneiss and volcanics is the CMDF complexly rolling low angle surface. Where observed the fault varies from a thin gouge (on the west side of the hill) to a strongly brecciated zone 2 to 25 feet thick. The thicker zones commonly have some FeO_x staining. The fault surface itself is complexly cut by later faults-some with a NNW trend, but most with an ENE trend as we see on the high ridges. The structural complexity of the region can be appreciated when one maps these numerous cross-cutting faults. The Picacho Mine is just over this domal hill where the CMDF appears to dip northward off the hillside.

From the hill, the dark peaks seen on the right horizon are in the Trigo Mountains, where detachment faults are present (Garner and others, 1982). Other neighboring ranges such as the Midways (Berg and others, 1982), Castle Domes (Logan and Hirsch, 1982; Gutmann, 1982; Gordon Haxel, pers. commun.), Kofas (Dahm and Hankins, 1982), Mohawk Mountains (Haxel and others, 1982; Mueller and others, 1982), and Baker Peaks-Wellton Hills (Pridmore and Craig, 1982; Pridmore and others, 1983) also contain well developed detachment faults and detachment-related deformation. Detachment faulting in the Picacho Peak region is thus an expected element of the crustal structure of the area.

Return to vehicles.

20.4 Note the intensely shattered Marcus Wash Granite on the west side of the road and Quechan Volcanics on the east. The CMDF projects directly under the road. The recent drill roads and holes were completed by Gold Fields to explore this zone's gold potential.

20.6 STOP 2. Examine brecciated Marcus Wash Granite at Detachment Fault.

Here we will examine the character of the CMDF where Marcus Wash Granite comprises the footwall. We will find that the Quechan Volcanics have moderate to steep dips here (caused by normal faulting) but that the contact with the underlying granite is nearly flat. Geometric relationships such as this convinced us that this contact is a detachment fault, despite its lack of a cataclastic microbreccia. Note that the upper plate Quechan Volcanics are not penetratively deformed like the Marcus Wash Granite. The contact does have a zone as much as 20 feet thick of brecciation, intense fracturing, low angle and high angle faulting, and local weak hematite and MnO_x staining. In one outcrop we can examine and discuss lenticular fault wedges, which Adams and others (1983) noted were typical of detachment fault zones and of deformation in lower plates of detachment faults.

We will walk a short loop here, starting down the wash. We encourage you to take careful notice of this zone, as we will compare it to the Picacho San George orebody which occurs in a very similarly deformed zone, but is also silicified, weakly pyritized and FeO_x stained, and is gold-bearing.

Return to vehicles.

21.1 Note the shattered and FeO_x-stained gneiss and schist in the wash to the west of the road. The CMDF dips eastward here under the road.

21.2 The CMDF crosses under the road to the east. As we drive upwards through a small saddle, we pass into the lower plate below the zone of brecciation.

21.5 Entrance to Picacho Gold Mine which we will return to. Note that the wash on the west side of the road has intense shattering, brecciation, and FeO_x staining. This alteration increases for 500' northward where it is truncated by a post-detachment WNW-trending normal fault. This alteration is typical of the CMDF zone in the mine.

22.0 Where the wash intersects the road (from the right) note the tilted fanglomerate. This unit underlies the Quechan Volcanics. It is comprised of poorly sorted angular to sub-rounded clasts of Winterhaven Fm and the older gneiss. These sediments were probably shed from fault scarps, suggesting that extension pre-dated the Quechan Volcanics.

22.4 Turn left into Little Picacho Wash. Note the major normal fault at the turnoff which down drops Quechan Volcanics against Winterhaven Formation (a stratigraphic throw of over 500 feet).

22.6 STOP 3 Examine CMDF zone.

Here we will examine the nature of the CMDF where Winterhaven Formation overlies older gneisses. These outcrops of the detachment fault were first recognized by Tom Skaug, Lenny Sinfield, and Steve Koester.

In walking westwardly up Little Picacho Wash we can observe the typical character of the Winterhaven Formation near the CMDF. Here it is a predominately metasedimentary section. Note the numerous NNW-trending, mostly E-dipping normal faults which have formed a near chaos. Note also that these faults do not project southward across the wash into the gneisses because they terminate at the CMDF which runs down the wash. Note that the faults are mostly not listric. This exposure is suggestive of extension mechanisms like those shown by Proffett (1977) for the Yerington district in western Nevada and by Anderson and others (1983) for the Basin and Range province as a whole. As suggested by Proffett, multiple generations of normal faults can progressively rotate both the upper-plate units and earlier upper-plate normal faults.

On the south side of Little Picacho Wash note a knob-shaped hill which protrudes from the other lower-plate rocks 10 to 20 feet because of its greater degree of silicification. A sample of this hill contained .005 o/T Au, 50 ppm As, and 90 ppm Sb - values typical of waste rock within the Picacho Mine proximal to ore-bodies, except for a higher Sb/As ratio. A thin section of the sample displayed complete cataclasis of the rock. Fragments of brecciated, comminuted quartz, microcline, and oligoclase rest in a matrix of rock flour, secondary green biotite, clays and secondary quartz. This cata-clastic matrix has been cut by numerous quartz-opaque (hematite ?) microveinlets which show the opaque being latest in the paragenesis. Similar veinlets and textures were commonly noted in the upper levels of the Dulcina Pit in the Picacho Mine. The similar structural setting textural and lithologic similarities, and similar geo-chemistry suggest this zone was weakly mineralized by the same process that formed the Picacho orebodies. The optimistic explorationist will also note the thin cover of alluvial material on the N side of the wash, which could cover potentially similarly mineralized zones with commercial gold grades.

We can follow up the wash a short way further and note the basal Tertiary unit in the region, the basalt of Little Picacho Wash and the overlying fanglomerates.

Note their steep dips and the fact that they do not project across the wash due to truncation against the CMDF. Note that they are much less deformed than the Winterhaven Formation, but they have been rotated by the detachment-related deformation. This relationship suggests that significant detachment faulting occurred prior to deposition of these two rock units.

From here hike southward over the hill of cataclasized gneiss and drop into a small arroyo, which has an excellent outcrop of the CMDF microbreccia ledge. In walking east along this small arroyo note small scale structures above and along the detachment fault. There are some minor listric faults here which terminate at the CMDF microbreccia ledge. Note also several small ENE-trending strike-slip and normal faults which offset the fault surface .5 to 2 inches. Lesser NW trending faults can also be seen. These small scale structures mimic the large scale structures which have complexly deformed the initial detachment fault geometry. Similar deformation has cut the initial Picacho orebody into smaller preserved pieces which are now being mined.

Following down this eastward trending arroyo we intersect another side canyon. At the intersection we can observe a glistening surface of microbreccia 1 to 2 inches thick with an underlying layer of rubbly brecciated breccia. Upstream from this exposure a small gorge exposes the essential elements of the faulting scenario, showing Winterhaven Formation complexly faulted onto the detachment surfaces.

Return to vehicles. On the way out of the wash, note the repeated beds of Winterhaven Formation.

22.8 Turn left back onto Picacho Road. We will now drive northward through a complexly fault-repeated section of Quechan Volcanics. One can appreciate the difficulty in determining the true thickness of the formation. Much of it is massive in character, but some relict beds can be seen with variably steep dips.

23.9 Note that where wash enters from left there are remains from an old gold mining effort.

24.0 STOP 4. Examine detachment fault with anomalous gold.

Park on right side of road. Note the exposure on the opposite side of the road (west) shows strong yellow-brown bleaching alteration and intense development of lensoidal shaped bodies bounded by numerous low to moderate-dipping faults (Hillemeyer, 1984; Adams and others, 1983). This alteration and deformation style exemplifies another character of the CMDF. The regional map relationships shown by Haxel (1979), Crowe (1973), and Drobeck and others (1986) indicate to us that this zone is also the CMDF. However, no one discreet micro-breccia ledge has been found (although it could be buried slightly below the wash). It is possible that the CMDF occurs here as a thick zone of distributive extensional shearing.

From here hike eastward through a small saddle of older leucogneiss. Note the small outcrop (next to claimpost) of gneiss which is intensely fractured but not brecciated. It has minor quartz veining and late ankerite staining on fractures. Follow down the hill-side and cross the wash. Here we can observe bold outcrops of leucogneiss with variable degrees of fracturing and minor seams of breccia. Keep these out-crops in mind when we visit the San George Orebody at Picacho.

Walking up the gully eastward, note a N45°W, 75°SW fault with an even greater degree of brecciation and weak argillic, silicic, and trace FeO_x alteration. Then cross up over the small hillside here to a spectacularly displayed cataclasite microbreccia ledge outcrop of the CMDF. This outcrop is similar to the Little Picacho Wash exposure of the CMDF. It provides compelling evidence for the relationship between detachment faulting and gold mineralization. A sample of the microbreccia ledge contained .070 o/T Au, 355 ppm As, and 12 ppm Sb - identical element concentrations as seen in the Picacho orebodies. By observing this low-angle contact curving around the small basin to the east we can note that the microbreccia ledge is not always present at the fault surface. Note also the post-detachment faults which have cut the CMDF.

Return to vehicle and drive back to the Picacho Mine.

26.2 STOP 5. Optional stop if time permits.

Turn right into Picacho Mine. The wash that we cross on the way into the mine displays intensely fractured and partially brecciated gneisses. Our mapping suggests this outcrop is only 10 to 30 feet below the CMDF. It is very similar to the gold ore that was mined from the upper levels of the Dulcina Pit.

26.4 STOP 6. Picacho Mine

The Picacho Mine is presently operated by Chemgold, Inc. and Tom Wood is the General Manager. The geologic and exploration community would like to thank Mr. Wood for his graciousness and patience in allowing dozens of groups to tour his property in the past four years. Our work would not have been possible without his consideration.

The Picacho Mine was carefully studied by Harris and Van Nort (1975) during their review of the property in the mid 1970's. Their detailed descriptions made our interpretations and conclusions possible.

Historically the mine produced on the order of 150,000 oz. of gold from underground workings between 1860 and 1910 (Harris and Van Nort, 1975; Van Nort and Harris, 1984). Chemgold Inc. has been operating the mine since 1981 as an open-pit operation. Reserves in early 1985 were 9.7 million short tons grading .038 o/T gold (1.3 ppm). The present mining rate is approximately 100,000 tons of ore per month with a 1:1 stripping ratio (Wood, pers. commun., 1985). The ore is strongly oxidized by weathering so that gold occurs in the free state. Most of the gold is between 10 and 100 microns in size making the ore readily amenable to heap leaching. The pronounced brecciation and weathering of the rock make the ore very crumbly so that crushing is unnecessary. These favorable features, in combination with a very efficiently run operation, allowed Chemgold to produce gold at approximately $125/oz. in fiscal 1984-5.

The Picacho Mine is comprised of four major orebodies: the Dulcina, Apache, San George, and Diablo (FIGURE 1). We will drive through the mine complex to the San George orebody first.

SAN GEORGE AREA

The San George area is just beginning to be developed, and a circular pit 800 feet in diameter and 100 feet deep is planned. It has been mapped by Liebler (1986) as shown on FIGURE 2. The trace of the CMDF here is not linear but curves around through the area, and it is this contact upon which the planned pit is centered (FIGURE 2). The old timers must also have known the importance of this contact, as numerous prospect pits are scattered in the area, at and near the contact. The CMDF juxtaposes Quechan Volcanics of the upper plate against pre-Tertiary gneisses of the lower plate. This low-angle contact can be seen by standing near the old decline and looking northwest up a small wash. The contact between the deep red colored volcanics and the weathered limonitic-argillic gneiss can be traced up and down the walls of the wash. Approximately 400 feet up the wash is a small prospect pit exposing fractured lower plate rocks, and gold was observed in a mass of red earthy hematite in a hand sample from this outcrop.

The outcrop in the immediate vicinity of the decline is a good example of the typical lower-plate silicified breccia which is so distinctive of the San George area. In thin section, we see that the matrix is made of very fine-grained quartz, with hematite and pyrite. Gold has been seen in this quartz breccia matrix in thin sections from similar rocks in this area. Gold has also been seen (in thin section) in breccia located along high angle fault contacts between volcanics and gneiss.

The most impressive features of the San George orebody are its intense brecciation of the leucocratic gneiss along the CMDF, the strong silicification, and the FeO_x staining from weathering of pyrite and hematite. The ore zone is very similar to the CMDF exposure we visited first today where Quechan Volcanics were faulted down onto Marcus Wash Granite. Rheologically, this older

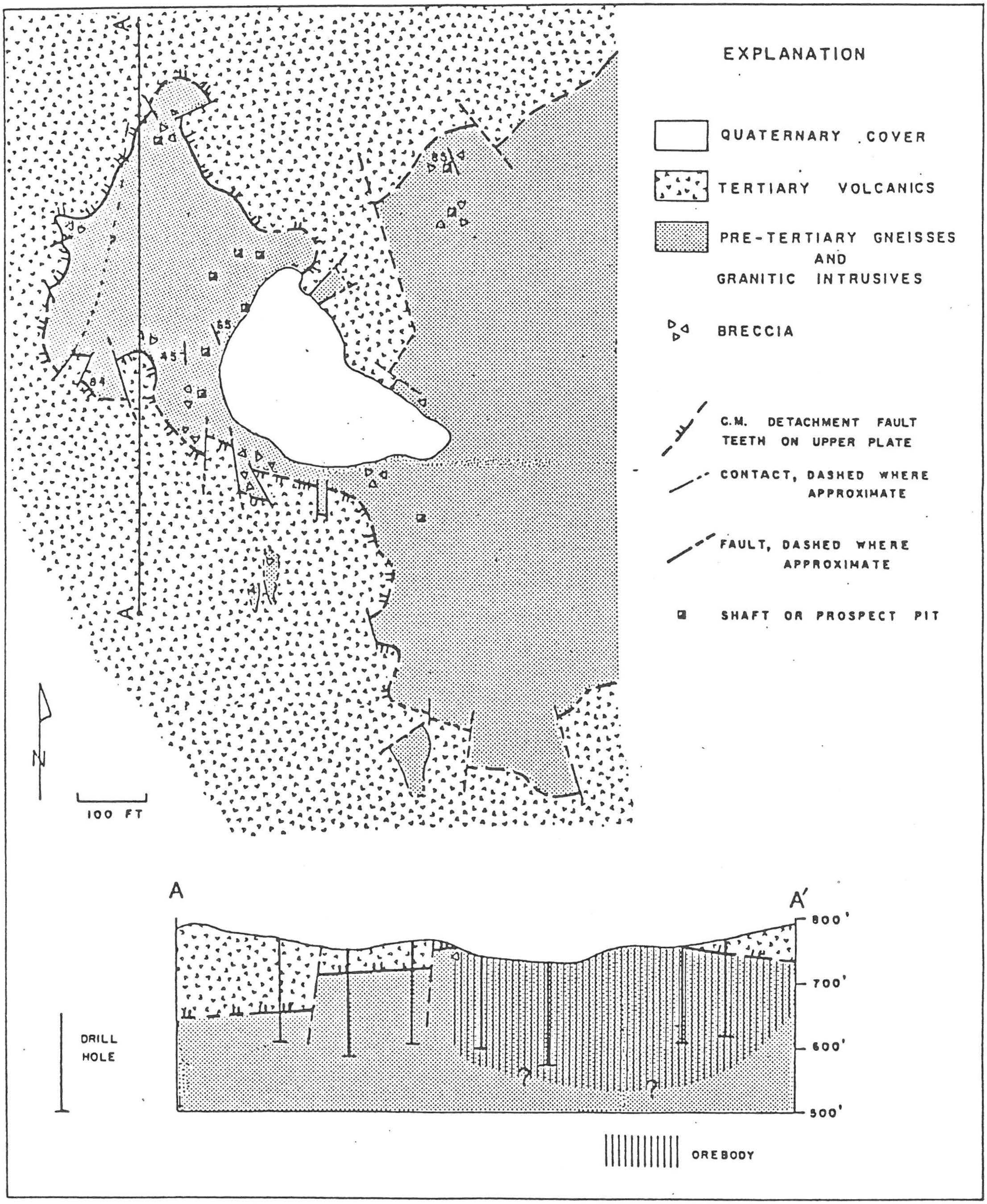


FIGURE 2. Geolgoic map and section of the San George orebody of the Picacho Mine from Liebler (1986).

leucogneiss breaks much like the Marcus Wash Granite, forming thick ravelly breccias at the CMDF. Thus, the exposure we visited earlier has been adequately structurally prepared, but unfortunately inadequately mineralized to make ore. Another similarity between these two stops on the fieldtrip is the lack of a microbreccia ledge. This feature could be explained in two ways:

a) A microbreccia ledge had formed earlier in the history when Winterhaven Formation was atop the fault, but as extension continued and isostatic doming occured, the microbreccia ledge was faulted when Quechan Volcanics were brought down to the CMDF.

b) The detachment fault here, at STOP 2, and on the W side of the road at STOP 4, formed as a thick zone of penetratively deformed rock, whose deformation fades upwards.

From the San George we will proceed back to the Apache Pit. As we drive back, note the low angle contact between the tilted Quechan Volcanics and the underlying gneisses on the west side of the road. Note also the 100 foot high hill on the east comprised of barren lower plate gneiss. The hill is a post ore horst. We will be able to observe its bounding fault in the Apache Pit.

APACHE PIT

The Apache Pit was the first major orebody produced by Chemgold. It has been described by Drobeck and others (1986):

> "The Apache orebody occurs on the southwest side of the mine complex (FIGURE 1). The northern portion of the orebody has been mined out, but the southern extension is still being mined. The northern portion produced roughly 450,000 short tons grading .05 o/T (1.7 ppm) from a pit 155 m long, 60 m wide, and 25 m deep (FIGURE 3).
>
> The mined orebody was oriented approximately north-south and dipped 25° to the west, although its shape was somewhat irregular due to post-ore normal faults. An unknown, but significant, amount of gold was produced from a 25-30° west-dipping decline shaft and stopes during the turn-of-the-century operation. The workings are no longer accessible but were described by Van Nort and Harris (1984). They described the mineralization as a breccia of Precambrian (?) and Tertiary volcanic clasts in a red-brown matrix of cataclastic Precambrian (?) rock fragments and rock flow. They found the matrix to be cemented by Na-montmorillonite derived from volcanic ash. Their sampling showed both Precambrian (?) and volcanic clasts as well as the matrix to be mineralized with gold. Hence, they concluded that the age of the mineralization must be post-volcanic.
>
> Mapping done in this study has shown that the CMDF occurs in the west side of the Apache Pit but has been complexely cut by northnortheast-striking post-detachment normal faults. Like the Apache breccia, the CMDF dips westward here. Hence, we suggest that this mineralized rubble is the CMDF, although its mineralogy and coarse breccia texture are atypical of detachment faults. We have

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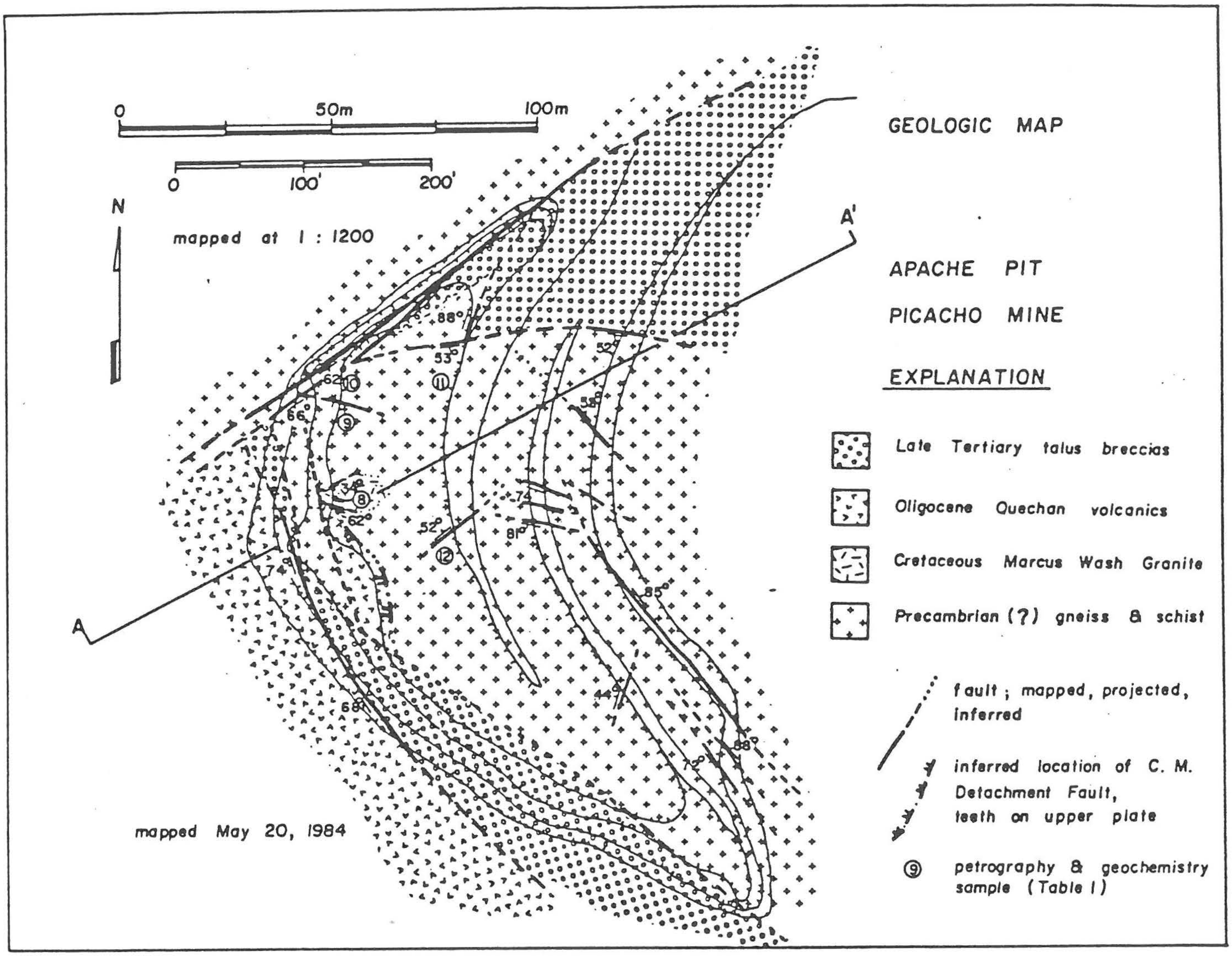

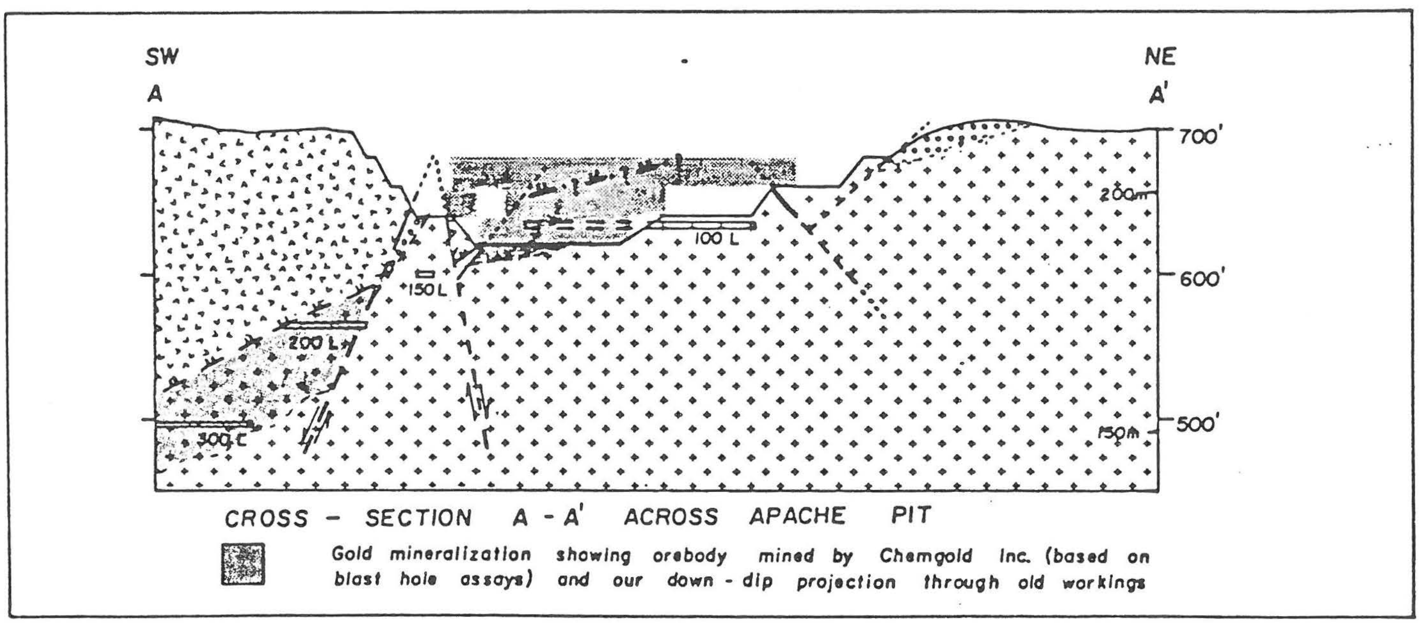

FIGURE 3. Geologic map and section of the Apache Orebody of the Picacho Mine from Drobeck and others (1986).

no ready explanation for the montmorillonite occurrence. This area may be one where the CMDF was very close to the surface during some of its motion or was strongly affected by later, near-surface normal faulting and weathering.

Timbers from the old decline are still visible on the west wall of the Apache Pit. They follow a dike of silicified Marcus Wash Granite (FIGURE 3). This dike has breccia fragments of Precambrian (?) gneiss included within it and is intensely fractured and moderately brecciated. It is well silicified and grades .170 o/T (see sample 8, TABLE 1). The metamorphic rocks surrounding the dike are only weakly mineralized and are less brecciated. A nearby sample of schist (#9 - see FIGURE 3) is only moderately brecciated, but significant strain was accommodated by bending, recrystallizing, and slippage along cleavage planes of biotite. The sample has no cataclastic rock flour. The breccia matrix is weakly mineralized with hematite but the sample only grades .010 o/T or .34 ppm (TABLE 1).

The contrast between these two nearby samples reiterates the importance that the host rock has in determining gold grades. The granite's style of strain was to shatter, forming excellent porosity for mineralizing solutions. Biotite in the schist allowed strain to occur with much less brecciation. The biotite also appears to have clogged pore spaces and hence, the schists and some gneisses were less receptive to mineralizing solutions. This relationship of more gold and more intense brecciation in the granite than the metamorphic rocks is evident from TABLE 1 (Marcus Wash is rarely waste in the mine).

Much of the Apache orebody that was mined by Chemgold was talus breccia that was shed off the large eastnortheast-striking normal fault on the north end of the pit (FIGURE 3).

The coherent hill of gneiss on the north and up-thrown side of the fault is typical of lower-plate metamorphic rocks below the CMDF zone. As this upthrown hill is surrounded by the four Picacho orebodies (FIGURE 1), it appears that there probably was a hypogene orebody on this hill that has been eroded. Some of it was preserved as the talus-breccia ore. The hill on the east side of the Apache Pit where the old mill stands may also have had hypogene ore that contributed to the talus breccia ore. Thus, the Picacho Mines may well have been one continuous orebody before the post-ore faulting. This orebody would have had rough dimensions of 925 m by 55- m by 20 m, or roughly 27 million short tons."

After we review the Apache Pit, we will drive back to briefly review the Dulcina Pit which has produced a large percentage of the ore so far produced by Chemgold Inc. Our study mapped the upper level of this pit when it was started in early 1984. We have been unable to return to map it since its greater development. It has been described by Drobeck and others (1986) based on this work in the upper level:

"The Dulcina contains ore around the old Dulcina glory hole and related underground workings. These workings were mined out by the open pit operation. It also contains the smaller Mars and Venus orebodies referred to by Van Nort and Harris (1984). The approximate dimensions are 400 m northeast-southwest by 150 m northwest-southeast by 15 to 40 m thick. Although the orebody is irregular, its general shape is tabular, with unaltered and unmineralized Quechan Volcanics covering the ore. The orebody occurs within the CMDF zone. The bottom of the orebody is crudely planar, dips northwesterly 10 to 20^{o}, and is marked by a decrease in gold, brecciation, and oxidation (Wood and Samuels, pers. commun., 1985). Some good gold grades persist downdip along this tabular zone underneath the leach pads but this rock is not considered ore because it is less oxidized and has a very high stripping ratio.

The ore in the Dulcina occurs as a mixture of brecciated Marcus Wash Granite and Precambrian (?) gneiss with lesser talus breccia ore. Much of the ore is so intensely brecciated and hematite-stained that determination of ore host rock is difficult. Our mapping indicated that volumetrically more ore is brecciated granite than Precambrian (?) metamorphic rocks in the upper benches. In places the breccia is so rubbly and weathered that it is difficult to discern from talus breccia made of lower-plate clasts. Van Nort and Harris (1984) and our petrography (TABLE 1) indicate a close association between degree of cataclasis and gold grade. This relationship indicates that structurally developed porosity was important in allowing passage of mineralizing fluids. The bottom of the ore zone coincides with the bottom of the CMDF zone of brecciation and a corresponding decrease in porosity.

The breccia matrix of the ore was mineralized with pyrite, hematite, and gold. The pyrite has been oxidized to hematite. The hematite pseudomorphs after pyrite are restricted to brecciated rock flour, fractures through clasts, and, to a much lesser extent, grain boundaries. The hematite pseudomorphs and rare unoxidized pyrite occur as subhedral to euhedral grains that are not brecciated by the brecciation event. Petrographic and geochemical analyses of the mine rocks indicate a close relationship between the amount of hematite (most as pyrite pseudomorphs and some as specular hematite) + goethite and the amount of gold (TABLE 1). The reddish stain from hematite + goethite is a guide to ore (Stannus, pers. commun., 1983). Van Nort and Harris (1984) had concentrated pyrite from less oxidized Dulcina ore and found that it contained nearly all the gold in the sample. Polished sections have shown that the gold occurs within oxidized pyrite pseudomorphs and also along fractures due to supergene remobilization. These observations indicate that the gold was precipitated cogenetically with pyrite and that this mineralization occurred near the end of, or after brecciation. Intense oxidation by weathering remobilized some of the native gold.

Much of the ore and waste in the Dulcina has a slight greenish-black cast that was originally mapped as chloritic alteration. Petrographic inspection of these samples found no chlorite. The coloration is due to a mixture of fine-grained hematite on fractures and strong supergene sericitic alteration of plagioclase.

The paragenetic sequence of alteration and mineralization in the Dulcina orebody is: 1) brecciation, 2) gold and pyrite with rare silicification and hematite veining, 3) hematite as replacements of pyrite and biotite, 4) post-ore carbonate veinlets,, 5) supergene redistribution of some gold, and supergene alteration of plagioclase to sericite and clay (TABLE 1)".

Return to the vehicles and then Yuma.

PICACHO PETROGRAPHY SUMMARY

	SAMPLE	ROCK TYPE	PRIMARY MINERALS: PLAGIOCLASE	QUARTZ	K - SPAR	BIOTITE	SPHENE	PYROXENE	GARNET	SECONDARY MINERALS: SERICITE	CLAYS	CHLORITE	QUARTZ	CARBONATE	PYRITE	HEMATITE	LIMONITE	BIOTITE	TEXTURE: CATACLASIS	BRECCIATION	FRACTURING	AU o/T	AS ppm
ORE SAMPLES	7	mw	■	■	■					•	•		◪			◪	◪		■	■	■	.210	80
	8	mw	■	■	■					•						•	◪		■	■	■	.170	240
	13	mw?	■	■	■	•			•	◪	■					■	•		■	■	■	.045	380
	15	p€?	■	■	■	◪			•	◪						■	◪	•	■	■	■	.170	420
	20	p€	■	■	■	•				■	•	•				◪	◪		■	■	■	.045	380
	22	p€	■	■	■	■				■	◪					◪	◪	•	■	■	■	.195	470
	25	p€?	■	■	■	•				◪	•					◪	◪		■	■	■	.045	280
	29	mw	■	■	■	•			•	■			■			◪	◪		•	•	■	.105	190
	30	p€	■	■	■	■				◪	■					◪	◪		■	■	■	.105	140
	31	mw	■	■	■				•	◪			◪	•		◪	■	•	■	■	■	.125	210
WASTE SAMPLES	11	p€	■	■		■		•	•	◪	•					•						.005	80
	12	p€	■	■	■	•				◪	◪					•				•		.010	260
	16	p€	■	■	■	◪			•	◪	•			•		◪	◪					.010	230
	26	p€	■	■	■	•			•	■	•					■	◪		■	■	■	.005	200
	32	p€	■	■		■	•	•	•	◪		■			•							--	70
	33	p€	■	■		■		•		•	■			•		•					■	--	100
	34	p€	■	■	■					■	•			•		◪	◪			•	■	--	100

Primary minerals: ■ +10% ◪ +2% • tr

Secondary minerals and texture: ■ strong ◪ moderate • weak

TABLE 1. Summary of mineralogy, textures, and geochemistry of ore versus waste samples from the Picacho Mine. Note the contrast in cataclasis and FeO content of ore versus waste. Much of the hematite occurs as pseudomorphic replacements of pyrite subhedra. From Drobeck and others (1986).

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GNEISSIC HOST ROCKS OF GOLD MINERALIZATION AT THE PICACHO MINE, SOUTHEASTERN CHOCOLATE MOUNTAINS, SOUTHEASTERN CALIFORNIA

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LOCATION OF FIELD TRIP STOP

Park at the historic monument near the entrance to the active Picacho mine, to the west of the Picacho Road which connects Winterhaven, California, and the Picacho State Park along the Colorado River. The cemetery for the old mining camp is located across the wash.

GNEISSIC ROCKS

The various lithofacies of the gneiss unit that hosts the gold mineralization at the Picacho Mine are unmineralized, relatively unaltered, and well exposed within a short walking distance from where the vehicles are parked. The majority of the host gneiss at the mine consists of intensely brecciated augen gneiss and, less commonly, aplite and pegmatite dikes and mafic schist (Harris and Van Nort, 1985). Where unaltered, these rocks consist of, in order of decreasing age: 1) interlayered hornblende-biotite schist and biotite-rich quartzo-feldspathic gneiss; 2) hornblende-biotite augen gneiss characterized by tabular, pinkish alkali feldspar augens, bluish quartz, and conspicuously large (few millimeter) euhedral sphene; and 3) sparse white to pinkish weathering aplite and pegmatite dikes that intruded the older gneiss. Some aplite dikes are cut by and locally appear to grade into small, sulfide-poor, milky quartz veins.

A Proterozoic protolith age has generally been assumed for these various gneissic rocks. This age assignment for the gneiss protolith was based largely on the high grade of metamorphism and on the general similarity of the augen gneiss to Proterozoic porphyritic monzogranites, particularly the 1.4 b.y. anorogenic granitoids. Tosdal and others (1985, 1986) have suggested that the gneisses are highly metamorphosed derivatives of Middle and Late Jurassic granitoids known as the Kitt Peak-Trigo Peaks superunit that is widely exposed in southeastern California and southern Arizona. The evidence for this hypothesis is summarized below.

The Middle and Late Jurassic granitoids constitute a compositionally-expanded suite composed principally of melanocratic and mesocratic biotite-hornblende diorite, mesocratic hornblende-biotite porphyritic granodiorite, and biotite-bearing leucogranite which locally grades into pegmatite (Tosdal and others, 1986). The porphyritic granodiorite, the most widespread and distinctive unit of the granitoid suite, is characterized by pink alkali feldspar phenocrysts, locally with a lavender tinge, local bluish quartz, and conspicuous millimeter-size, hatchet-shaped sphene crystals. In several ranges 10 to 50 km to the north, this suite of rocks is deformed (Tosdal, 1986) to gneiss that strongly resembles the gneiss at the Picacho Mine. The porphyritic granodiorite has yielded concordant U-Pb zircon ages of 165 m.y. from three range to the north (L.T. Silver, in Powell, 1981; Tosdal, unpublished data, 1986). The leucogranite phase is not as well dated; a concordant U-Pb zircon age of 158 m.y. has been determined for a leucogranite dike in the Trigo Peaks area, southwestern Arizona, some 50 km to the north (Tosdal, unpublished data, 1986).

U-Pb zircon geochronology, in progress, on the meta-granitic rocks near the Picacho Mine should resolve the protolith age.

The Late Cretaceous granite of Marcus Wash (Haxel, 1977; Haxel and others, 1985) is exposed a few kilometers to the east. Some of the unfoliated, muscovite-bearing, leucocratic dikes intruding the gneiss may be related to the granite of Marcus Wash.

DIRECTIONS TO EXPOSURES OF THE VARIOUS GNEISSIC ROCKS

All of the rock units described previously are well exposed within a short distance from the mine overlook. Walk south along the Picacho road to a wash. Walk north along the wash to examine the mafic schist and crosscutting aplite dikes. South along the wash, the augen gneiss is quickly encountered. If time permits, continue southward across the narrow gravel terrace to the larger hill, composed almost entirely of augen gneiss. Arroyos draining the hill provide good exposures.

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