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Field Guide to the Superior Region, Pinal County, Arizona

by: James D. Sell,
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) 229-4342

Guidebook for the
Arizona Geological Society
Fall Field Trip
October 28, 1995

Mark A. Miller, Field Trip Chairman
Rob Wm. Vugteveen, Guidebook Editor

Arizona Geological Society
PO Box 40952 Tucson, AZ 85717

Arizona Geological Society
P.O. Box 40952
Tucson, AZ 85717

October 28, 1995

Dear Field Trip Participant,

Welcome to the 1995 AGS Fall Field Trip to examine the Geology and Ore Deposits of the Superior District in Pinal County, Arizona. The trip is split into two sections with part of the group going underground at the Superior Mine, owned and operated by Magma Copper Company. Our hosts, Alex Paul and Matt Knight will educate us about geology and mining of the Superior Copper Deposit. At the same time, Jim Sell will be conducting a tour describing the surface geology of the Superior District. The road log that Jim has prepared is very informative and entertaining.

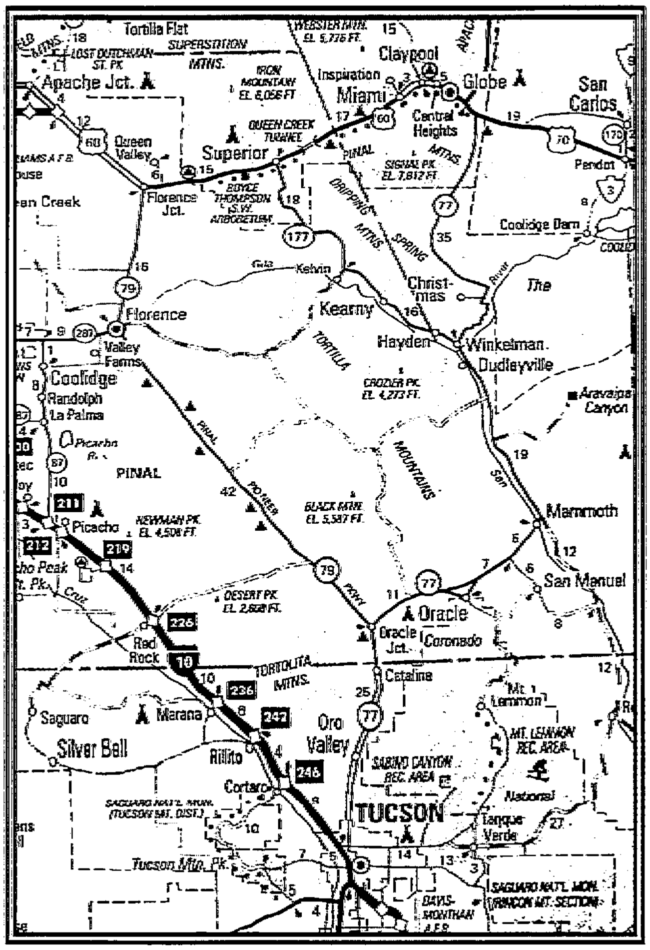
I would like to thank several people who have been invaluable in the preparation of this field trip and the guidebook: Jim Sell for assembling the guidebook and organizing the surface tour of the district, Kathee Harrigan at Asarco for word processing, and Rob Vugteveen for editing and desktop publishing. Without their help this event would not have been possible.

Enjoy the day!

Sincerely,

Mark Miller
Editor and Vice-President of Field Trips

Starting in **Tucson**, we'll follow
Arizona Highway 77 north to **Oracle Junction**,
Arizona Highway 79 northwest to **Florence Junction**,
US Route 60 east to **Superior**.



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Arizona Geological Society
Fall Field Trip, October 28, 1995
ORACLE JUNCTION – FLORENCE – SUPERIOR

Note, as the first freebie, you get the road log from Ina Road, however, you probably will not see the Guidebook until Oracle Junction, so this part is for your leisure trip in the future. Happy Outing!

Mile Post	Cumulative Mileage	
74.8	0.0	Ina Road at Oracle Highway. This log utilizes the GREEN Arizona milepost markers located each mile. From Tucson, the Oracle Highway has climbed several terraces of the Rillito River system and presently traverses over the outwash fans from the Santa Catalina Mountain Complex. The Santa Catalina Mountains (1-3 o'clock) are a metamorphic core complex. (Banks, 1976; Keith, 1980) The Tucson Mountains and Safford Peak (7-9 o'clock) are part of a volcanic complex (Mayo, 1963, 1968). Far away, Ragged Top and the Silver Bell Mountains (9-10 o'clock) peer through the haze. (See AGS Field Trip #10, 1981). At 11 o'clock, the Tortolita Mountain Range occupies much of the view (Banks, 1976, 1977). For the next several miles, note the profusion of townhouses, condos, and Circle K varieties of foothillies who live above the lower Tucson haze habitat. At the left end of the Tortolita Mountains, on a good day, the top of Picacho Peak can be seen (Shafiquillah, 1976). Picacho Peak in the past was a landmark for travelers leaving the Presidio de Tucson and making their way to the Pima Villages and thence to California via the Gila River. Now the Picacho Peak area is probably best known for the ostrich farm at its base.
77.2	2.4	Start to drop off the fan deposits. Excellent end-on view of Pusch Ridge (3 o'clock)--home of the Arizona Big Horn Sheep and the dissertation of McCullough (1963).

Mile Post	Cumulative Mileage	
79.0	4.2	The Cañada del Oro drainage has a wide outer flood plain which has been truncated, and then entrenched by itself, in the gravel-mudstone terrace fan deposits (which you passed through on the long curve between MP 78 and 79). Vegetation of mixed desert broom, mesquite, palo verde. As you continue north, note the two terrace development levels on your right. Pusch Ridge escarpment (3 o'clock).
80.5	5.7	Before the new road construction, there was an Arizona Highway Department roadside marker here (9 o'clock). *"Cañada del Oro. For earlier travelers, the road through this Canyon was one of the most dangerous to Arizona. Indians attacked lone riders and wagon trains along this route from Tucson to Old Camp Grant on the San Pedro River. Despite the Canyon's name, very little gold was ever found here."* Press on, but not too fast, as the Oro Valley police like to catch speeders along here and collect their own gold! Peering over the gravel deposits (2 o'clock), prior to traversing the bridge over the Cañada del Oro stream, you will note a ridge of the metamorphic complex exhibiting a large amplitude fold.
80.9	6.1	Bridge over Cañada del Oro. At 2:30 o'clock, looking down axial plane of the anticlinal fold (Pashley, 1963; McCullough, 1963).
81.5	6.7	Climbing out of Cañada del Oro, with the road alongside Big Wash cutting through dissected gravel-silt terrace deposits.
81.8	7.0	Good view (4 o'clock) of the anticlinal folding in metamorphic complex along lower slope of range.
82.0	7.2	View of terrace surfaces (9 o'clock).
82.2	7.4	The rough "granite" exposure (3 o'clock) at the foot of the Santa Catalina Mountains is the quartz monzonite (20-24 my) of Samaniego Ridge, as are the upper skyline crags (Banks, 1976; Creasey, *et al.*, 1976). In the Tortolita Mountains (9-11 o'clock), the low foothill granites are a younger phase of the Catalina Complex (Creasey, *et al.*, 1976; Banks, *et al.*, 1977).

Mile Post	Cumulative Mileage	
84.8	10.0	White scars (2:30 o'clock) in the Tortolita Mountains are marbleized Permian units being quarried for roof covering, front yard decoration, etc.
85.1	10.3	Ex-missile silo complex (2 o'clock). Sleep Tight, Big Brother was Watching Over You. Now it's a land fill area.
86.0	11.2	Welcome to Trailerville—Land of Sunshine and Hope. The Tortolita Land Plan Complex on left side of road expected "100,000 people by 1985". Buy now! Oops, may be too late in 1995 to get in on the ground floor, but you can still purchase a pink-roofed home back at Rancho Vistoso, or be an early one here.
87.8	13.0	Entering Pinal County. Horse breeder-training complex (2-3 o'clock) – a very nice addition to the visual impact of the area, however, the fences need repainting.
90.5	15.7	Junction with Arizona Highways 77 and 79, and our starting point for AGS Fall Field Trip, 1995, is one-half mile ahead.
91.0	16.2	Oracle Junction. See Arizona Bureau of Mines (now Arizona Geological Survey) Bulletin 176 (Peirce, H.W., 1976) for road log to Oracle and north along Highway 77, or see AGS Spring Field Trip of 1994.

RESET YOUR ODOMETER TO ZERO AT ORACLE JUNCTION.

91.1	0.0	Oracle Junction, take left road to Florence on AZ 79.
91.4	0.4	Entering Pinal Pioneer Parkway. Monument built of schist, gneiss, quartzite, granitoids, and quartz vein materials from Tortolita complex, plus odds and ends of epidote, azurite, malachite, and chrysocolla. Vegetation here is dominantly catclaw, mesquite, desert broom, various cholla, yucca, prickly pear, and hackberry (Wells, 1960).
91.5	0.5	Bridge over Big Wash. Note the ground cover difference between Parkway and outside of grazing fence. High fire fuel feed along the Parkway is easily set afire and then burns large swaths into outside grazing areas.
96.0	5.0	Black Mountain with Tortolita Mountains and Antelope Peak behind (1-2 o'clock). Galiuro Range across San Pedro River in far skyline (3-4 o'clock) (See AGS Spring Field Trip, 1994).

Mile Post	Cumulative Mileage	
98.0	7.0	Durham Hills-Owl Heads (10 o'clock) in near range of hills. On skyline is massive "granite" (grey) of Picacho Mountain complex (10-11 o'clock) (Yeend, 1976), with jagged volcaniclastic units (dark grey black) of Picacho Peak at far 2 o'clock. (In between, 65 miles away, in further background, are Table Top Mountains located southwest of the Sacaton Mine.) Note that the vegetation here at 3,400 feet has given way to palo verde, cholla, prickly pear, catclaw, greasewood flora.
99.0	8.0	Volcanics at 12 o'clock with former Titan missile site at base. As you go around the corner, you'll see it is now a ranch house area.
99.7	8.7	Conglomerates in curve roadcut (Ts of Banks, *et al.*, 1977).
100.3	9.3	Three Buttes at 9 o'clock. (Banks, *et al.*, 1977), map Tbasalt intruding Tos, older sediment, and Tys, younger sediments.
101.4	10.4	Junction; stay on Pioneer Parkway. The road left is Park Link Drive to Red Rock and Eloy. Ragged Top and Silver Bell Mountains in far distance (9:30 o'clock). (See Field Trip #15, AGS Fall 1994, "Bootprints"). Owl Head Buttes, 6 miles away at 9 o'clock.
101.9	10.9	Cadillac Wash Bridge with reddish conglomerates (Tos?) in right hand wash wall and bottom. Named many years ago for the brand new Cadillac which was caught in a desert rain runoff and washed downstream and buried by the sand in the days before bridges.
102.3	11.3	Low rolling slope, at 9 o'clock next to road, is a dike of Tertiary basalt with undifferentiated Tertiary sediments on both sides (probably Tys).
102.5	11.5	Conglomerate in roadcut on curve before Forman Wash Bridge.
104.0	13.0	Suizo Mountains (10-11 o'clock). Picacho Peak and Mountain in far background.
104.3	13.3	Olson Wash Bridge with Tertiary basalt in right side wash wall.
104.6	13.6	Roadcuts in "schist-gneiss" of Oracle Granite derivation.

Mile Post	Cumulative Mileage	
106.0	15.0	Vegetation at 2,800 foot elevation, giving way to greasewood (creosote bush), catclaw, palo verde, and saguaro assemblage.
108.0	17.0	Northern end of Durham Hills (10 o'clock) with pinkish Samaniego granite having a medium grey diorite border phase on last hill (11 o'clock). Entering magnetic sand project of Black Sands Iron Corporation. Do you have any stock???
110.0	19.0	Ninety Six Hills area (3 o'clock) and Picacho Peak Mountain (9-10 o'clock) showing through dense cover of palo verde and cholla forest. (What? A forest in this part of Arizona?)
111.6	20.6	Freeman Road cutoff to Dudleyville, with Pinal Schist hills (1 o'clock) cut by aplite, pegmatite, and dike of Samaniego diorite phase. Minor copper oxide occurrences.
114.0	23.0	Welcome to the Great American Pinal Parkway desert, with more saguaro now appearing.
115.5	24.5	Tom Mix Memorial rest area. *"Jan. 6, 1880 – Oct. 12, 1940... who's spirit left his body on this spot..."* No paved road and bridges then — just a dirt road and dips, which flipped his speeding vehicle.
117.0	26.0	Low hills (2 o'clock) of muscovite granite cut by numerous and diversified dikes of the 96 Hills SW complex.
117.9	26.9	Deep Well Ranch Road to left. Access to the Phillips Arizona State A-1 hole which bottomed at 18,013 feet, and the North Star Mine area.
		As expressed by Reif and Robinson (1981), the State A-1 penetrated 700 feet of alluvium, then stayed in granite wash (valley fill) to 3,879 feet. Then, granite to granodiorite (Unit 1) of 1.39 billion year age was cut to 10,761 feet. Unit 2, a muscovite granite with a 47 million year age, was encountered to 12,755 feet. Unit 3, a biotite hornblende gneiss of plus 1.5 billion year age, completed the run to 18,013 feet T.D.
		The two-mica granite of Unit 2 is highly brecciated and the base is probably the site of a large subhorizontal fault. Do you believe in large, or small, subhorizontal faults?

Mile Post	Cumulative Mileage	
		The North Star Mine area (Yeend, 1976) is in the low hills (10 o'clock) on north end of Picacho Mountains. Need to know more? Ask D. Hammer.
121.4	30.4	Leaving Pinal Pioneer Parkway.
125.0	34.0	Grayback Peak peeking through the forest at 3 o'clock.
127.6	36.6	Cactus Forest Junction. Note the 8-foot high round rock structure on the northeast side of the junction (look right). It is built out of altered and leached capping boulders with copper oxide. Probably from the Red Hills deposit off to the right. Also a few granite and latite boulders in the structure. Note flora change at 1,700 feet elevation to greasewood-cholla-saguaro format.
130.0	39.0	Superstition volcanic complex (1-2 o'clock) on far skyline, (Sheridan and Prowell, 1986.)
		North and South Buttes (3 o'clock), potential site of Buttes Dam of Central Arizona Storage Project. Note younger 'rift' volcanic complex behind the Buttes.
		Pinal Mountains (4 o'clock) is the far semi-rounded mass.
		Sacaton-San Tan Mountains complex of Balla, 1972 (10-11 o'clock).
		"F" Hill at Florence is the Poston Butte basalt (12 o'clock).
131.5	40.5	Ocotilla now appearing as part of the flora.
132.0	41.0	One-way road split. Keep right on AZ 79 North. Crossing CAP canal – the Lifeblood of Tucson!
133.0	42.0	Florence, Arizona. State Prison and fields on right. Do not pick up lady hitchhikers.
135.0	44.0	Poston Butte (11 o'clock), with rock pyramid on top. Basalt flows, tilted, with altered Precambrian granite at western base (AGS Fall Field Trip, 1973). Discovery outcrop of Asarco's Poston Butte Project, drilled with few holes and dropped, later picked up by Conoco (5 days ahead of Asarco's re-interest) and abundant drilling and $$$$$$ invested. Shaft and office building south of the butte; project put on the shelf. Now being drilled and evaluated by Magma Copper Company, and new home for Cori.
		Walker Butte cone at 9 o'clock.
135.2	44.2	New prison complex filling fields on right.

Mile Post	Cumulative Mileage	
135.5	44.5	Gila River Bridge. Associated flood plains of several stages, and wide inner terrace with shallow Gila River entrenchment.
135.9	44.9	ADH historic sign on left (west). *"Poston Butte – Final resting place of 'Father of Arizona', Charles D. Poston, born Kentucky, 1825, Arizona's first delegate to Congress is buried in accordance with his wishes atop the hill two miles west. It was to have been the site of Poston's Temple To The Sun, but that effort failed and he died in poverty in Phoenix in 1902. Not until years later were his remains brought to the place called Parsee Hill, but known to the local residents as Poston's Butte."*
136.4	45.4	Railroad crossing. Rails go upriver to Ray-Hayden-San Manuel.
136.8	45.8	Florence Federal Detention Facilities (former WWII POW camp) on left, followed by retirement trailers for sunshine and golf.
137.5	46.5	Near low hills (1 o'clock) of basalt interlayered with gravels of the Gila River system. Major skyline (2-3 o'clock) is mainly a volcanic-tuff-conglomerate complex of mid-Tertiary age. View (3 o'clock) of North and South Buttes in mid-background, with Gila River drainage in between. On far background to right of South Butte is the Grayback Mountain cone.
138.2	47.2	Rising out of the road (12 o'clock) is the Three Peaks of the Mazatzal Range, some 65 miles away.
139.0	48.0	Superstition Mountains volcanic complex (11-1 o'clock). Smog of Phoenix to left. Left side cliff face of Superstition is the Geronimo Head dacite, the oldest intrusive-extrusive of the complex. Note layered flows to right, then jumbled units which are the youngest of the complex and lie within the rift portion. Far right background is schist-gneiss Precambrian complex on the far side of the rift. As at the Buttes area, outflow units lap out onto the higher basement walls on both sides of the rift.
140.4	49.4	Road on the left to Arizona Farms. At the northeast corner of the junction, a local air-hammer driller (on State Lease) drilled through the surface sands and gravels, then a layer of basalt, and back into gravels. While daydreaming and drilling ahead, the hole ballooned on him and cuttings piled up behind the bit and he was stuck before he could

Mile Post	Cumulative Mileage	
		react. All tools and the rig were abandoned for several weeks before he returned and was successful in working the string free. Ah, those good olde days!
142.0	57.0	Increasing better views of Superstition Mountain in front. Near skyline masses at 3 o'clock are Precambrian Pinal Schist with rift volcanics peeking from behind. At 2 o'clock is small white outcrop at base of schist—a weakly altered porphyry having its share of drill holes in it.
147.1	56.1	Left side of road across fence are pits and piles left from an oil well test. The 20-inch hole cratered and the hole abandoned in the gravels.
148.0	57.0	Change in flora to greasewood with mesquite and ironwood in drainage.
148.3	57.3	Magma Arizona Railroad
149.0	58.0	Low hills in front (1-2 o'clock) are dacite of Geronimo Head resting on Precambrian granite. These are outside the inner rift boundary.
150.2	59.2	Florence Junction. Keep right to Superior on US 60 East.
150.7	59.7	Hardys Turquoise Factory on left.
	NOTE:	AZ highway marker number designation changed at the junction. Total cumulative mileage continues.
213.0	59.7	Hardys Turquoise Factory. Closer view of dacite (9 o'clock) at south side of Superstition Range. The volcanic unit rests on Precambrian granite and Apache Group.
214.3	61.0	Queen Valley Road to left, and crossing Magma Arizona Railroad. Stay on US 60 east.
214.5	61.2	Pink brown dacite hills (12 o'clock) resting on grey-green Pinal Schist on hills behind.
215.0	61.7	At 10 o'clock, a quick glimpse of valley with reddish dacite on left, gray-green schist on right. Beyond is jumbled volcanics in rift. Far skyline is Precambrian metamorphic complex. At 9 o'clock, a good view of Weaver's Needle within the Superstition Wilderness area.
215.9	62.9	9-10 o'clock. View of younger jumbled units within rift.
216.7	63.4	3 o'clock. View of outflow dacite block with Precambrian Pinal Schist in gulch.

Mile Post	Cumulative Mileage	
218.0	64.7	Climbing up through Pinal Schist.
218.6	65.3	Gonzales Pass. Occasional glimpses (9 o'clock) of jumbled volcanics in lowered rift zone, flanked on road side by Precambrian schist, with Precambrian metamorphics on skyline in back on northern side of rift.
219.2	65.9	Hulk of Picketpost Mountain at 12 o'clock. (Nelson, 1966).
219.5	66.2	12 o'clock. View into Superior with Precambrian basement and sediments through Pennsylvanian Naco Limestone overlain by Tertiary dacite with Whitetail Conglomerate here and there between the limestone and dacite. Tertiary Earlier Volcanics underlie the dacite to the north.
221.0	67.7	Roadcuts with schist overlain by red ash (Olbreg beds of Blucher (Sell, 1968) overlain by dacite and water-lain tuffs. These tuffs are found on schist for the next several miles on both sides of the road.
221.2	67.9	Roadcut in Blue Basalt of Blucher (Sell, 1968).
221.7	68.4	Mined bench cuts of water-lain tuff (1 o'clock) near road was used for flagstone and building blocks around Superior. On left, in roadcut, Precambrian Pinal Schist overlain by 30- degree east dipping red ash beds overlain by blue basalt, then cut by a 70-degree west dipping fault; then, the schist-red ash-basalt sequence repeated. Last third of roadcut is all blue basalt cut by numerous vertical fault breccia zones. On the initial portion of the roadcut, in the right (south) wall, a unit of red ash is draped over a faulted schist block, which is repeated as on the north wall.
222.0	68.7	9 o'clock. View of jumbled volcanics in rift at distance. Next several roadcuts in Blue Basalt.
222.2	68.9	Queen Creek Bridge with Blue Basalt in creek. Next several road cuts in Blue Basalt.
223.1	69.8	Entrance on right to Boyce Thompson Arboretum. A nice family picnic and hiking stop-over. (University of Arizona pamphlets).
223.2	69.9	Partial roadcut on right has Whitetail Conglomerate resting on Pinal Schist. Cuts on left are lower units of air and water-lain tuffs from the Picketpost volcano (3 o'clock).

Mile Post	Cumulative Mileage	
223.5	70.2	Roadside marker (right side). *"Picketpost Mountain – A landmark and lookout point during Indian Wars, site of outpost of Camp Pinal which was located at head of Stoneman Grade to the east. Soldiers protected Pinal City and the Silver King Mine from Apache raiders. It was the home of Col. William Boyce Thompson, mining magnate and founder of the Southwest Arboretum at the foot of the mountain."* Col. Thompson's house (castle) is the tile roofed edifice at 2 o'clock. Thompson formed Newmont Corporation as his holding company for investments in Magma, Inspiration, Bingham Canyon, Inco, etc., at the turn of the century (Hagedorn, H., 1935).
224.1	70.8	Roadcut of Quaternary Gila Conglomerate.
224.5	71.2	Roadcut of inner-rift volcanics. **STOP 1 ahead on right.**
225.1	71.8	**STOP 1.** Superior Airport. Park along the fence adjacent to airport building at top of rise on right. The sloping runway needs pilot adjustment when landing or taking off. Figures 2 through 5 show maps with all of the STOPS. References for district: Hammer and Peterson, 1968 Paul and Knight, 1995 Peterson, D.W., 1960, 1961, 1962, 1968, 1969 Peterson, N.P., 1963 Sell, 1995. Figure 1 is the geologic column for the district. We are standing in a basin filled by alluvium, Gila Conglomerate and inner-rift volcanics. Others have stopped here (Sheridan, M.F., 1968), however, you'll probably hear a somewhat different version.

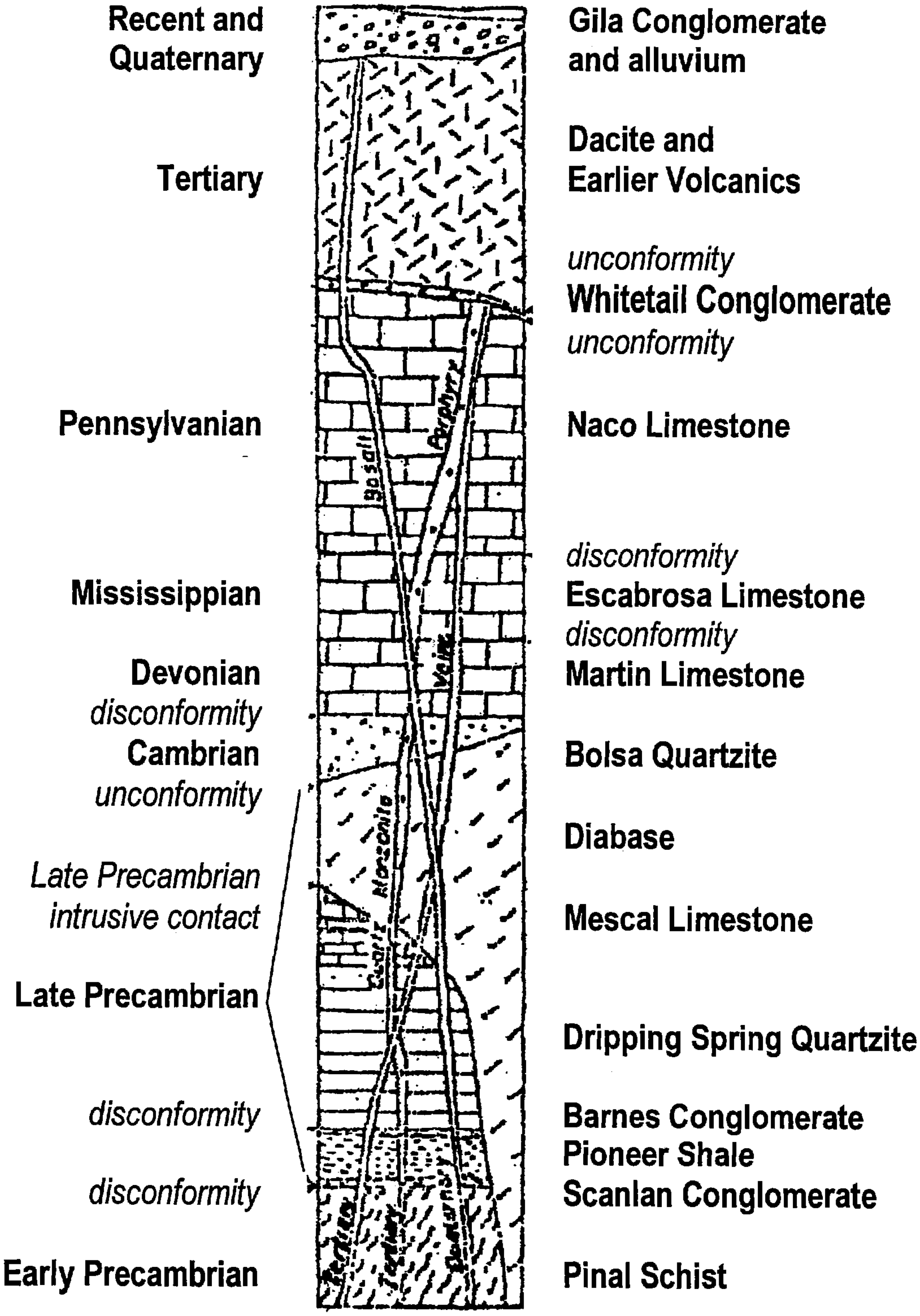

Figure 1.

Generalized geologic column in the vicinity of the Magma Mine.
(Revised from Figure 2 in AGS, 1981.)

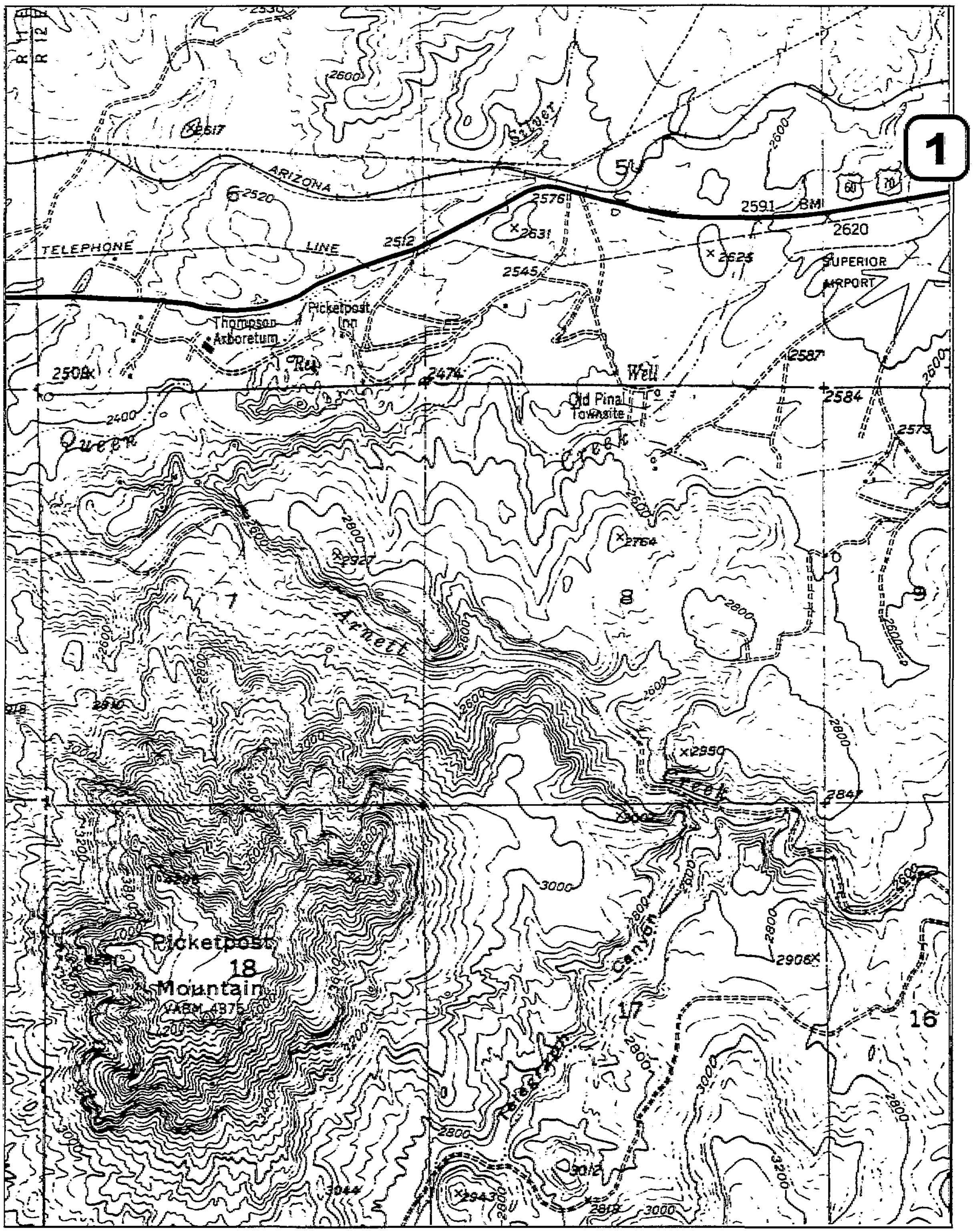

Figure 2.
Stop 1 is at the Superior Airport.

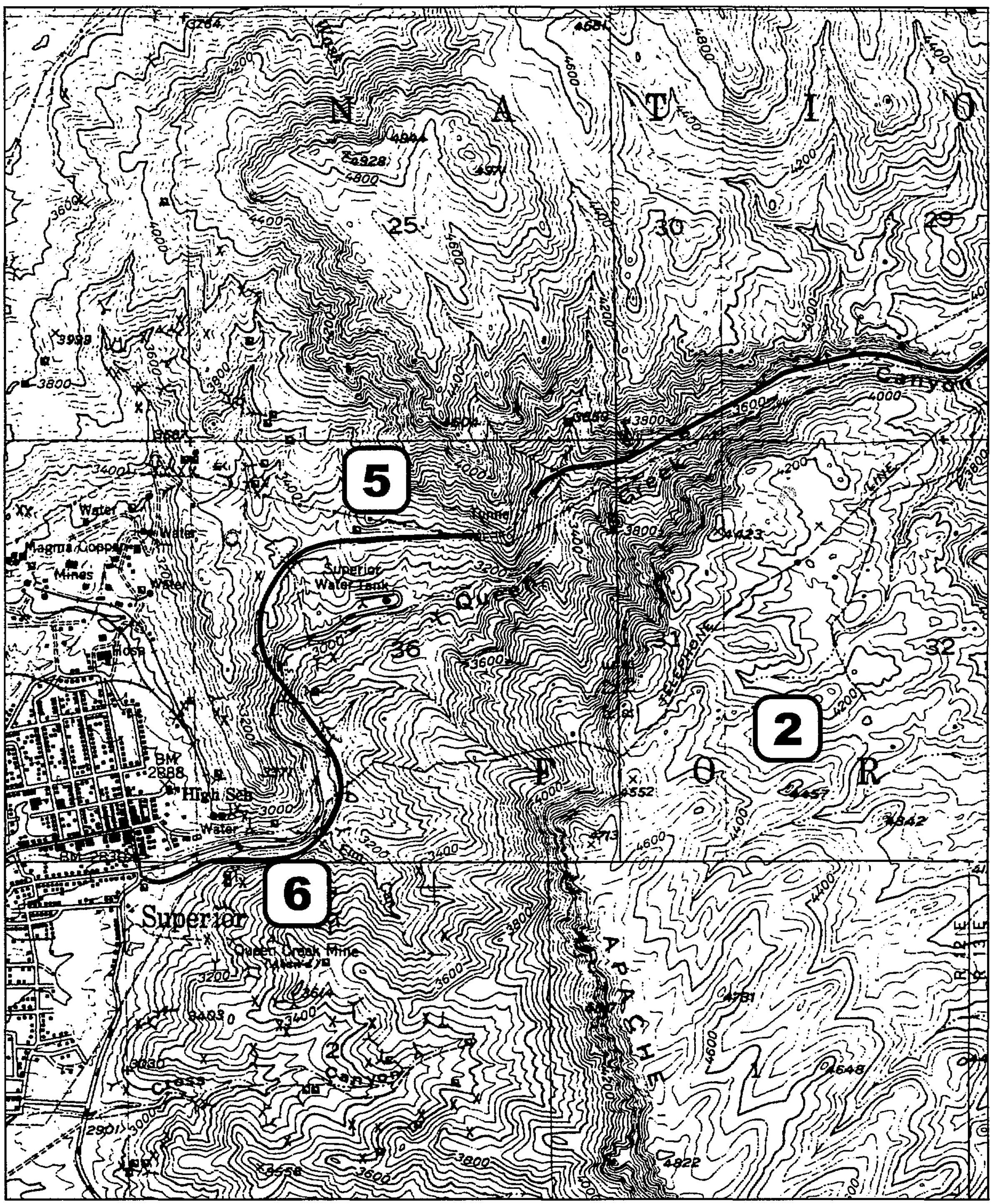

Figure 3.

Queen Creek Canyon and Stops 2, 5, and 6.

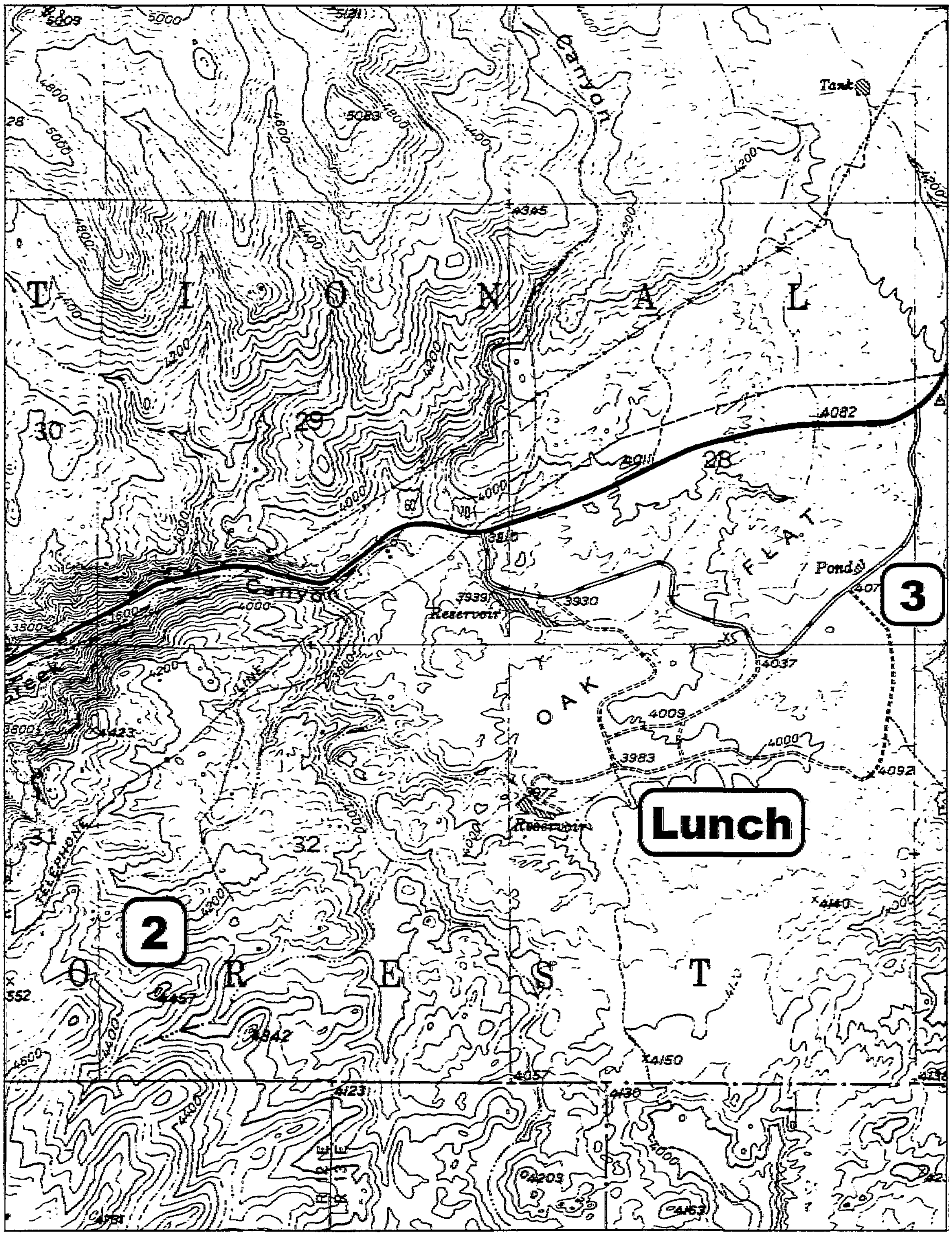

Figure 4.

The area over the Magma Mine and Stops 2, 3, and Lunch.

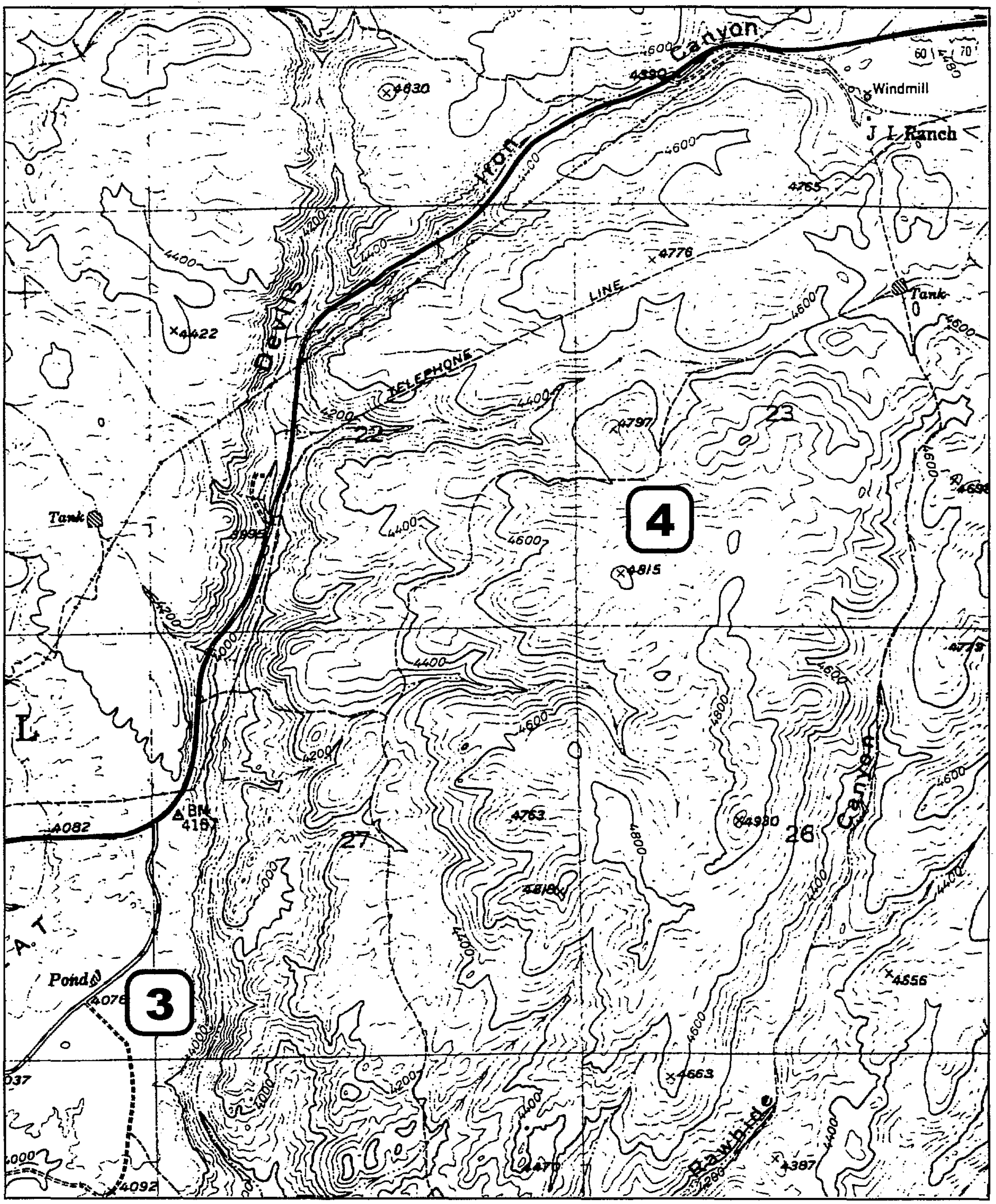

Figure 5.

The area of the Superior East project and Stops 3 and 4.

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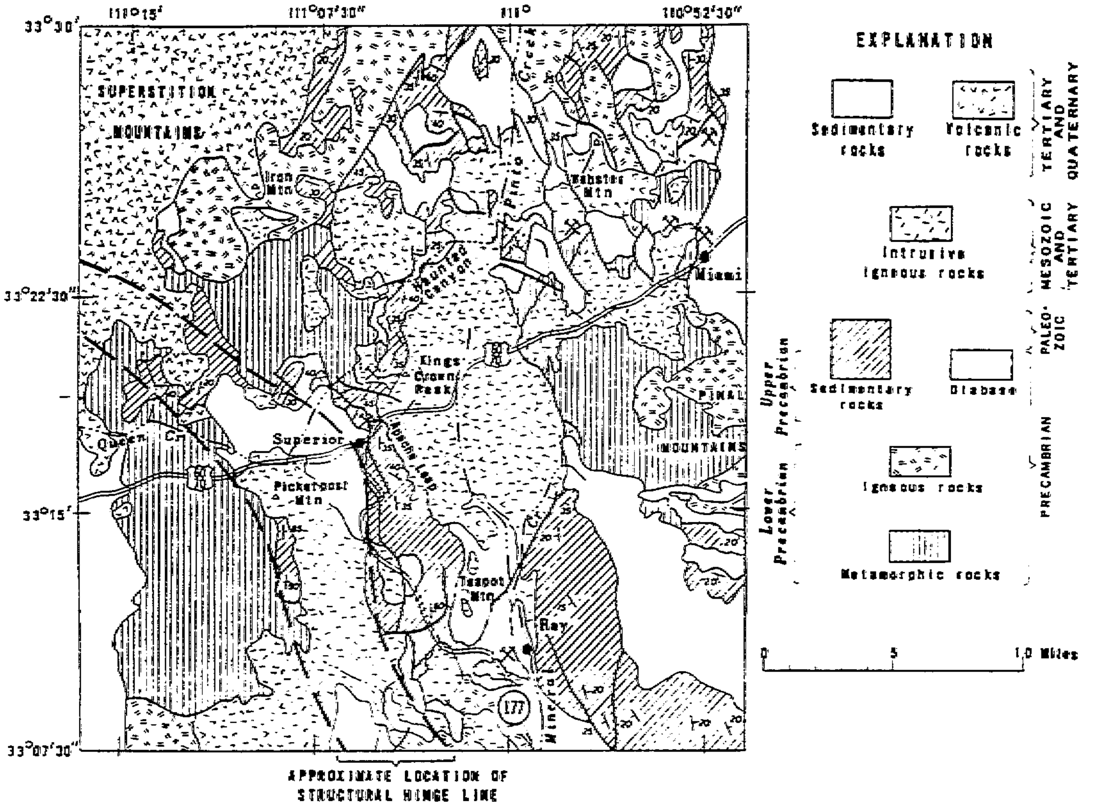


FIG. 1. *Geologic Map of the Region around the Magma Mine. Geology has been generalized, with modification, from the following maps and reports: F. L. Ransome (5), N. P. Peterson, (18), E. D. Wilson, et al. (11, 12), and D. W. Peterson (13, 17).*

Figure 6.

Geologic Map of the Region around the Magma Mine.
(Adapted from Hammer and Peterson, 1968)

We're inside the hinge zone of
Hammer and Peterson (1968) Figure 4,
and Keith (1986) Figure 5.

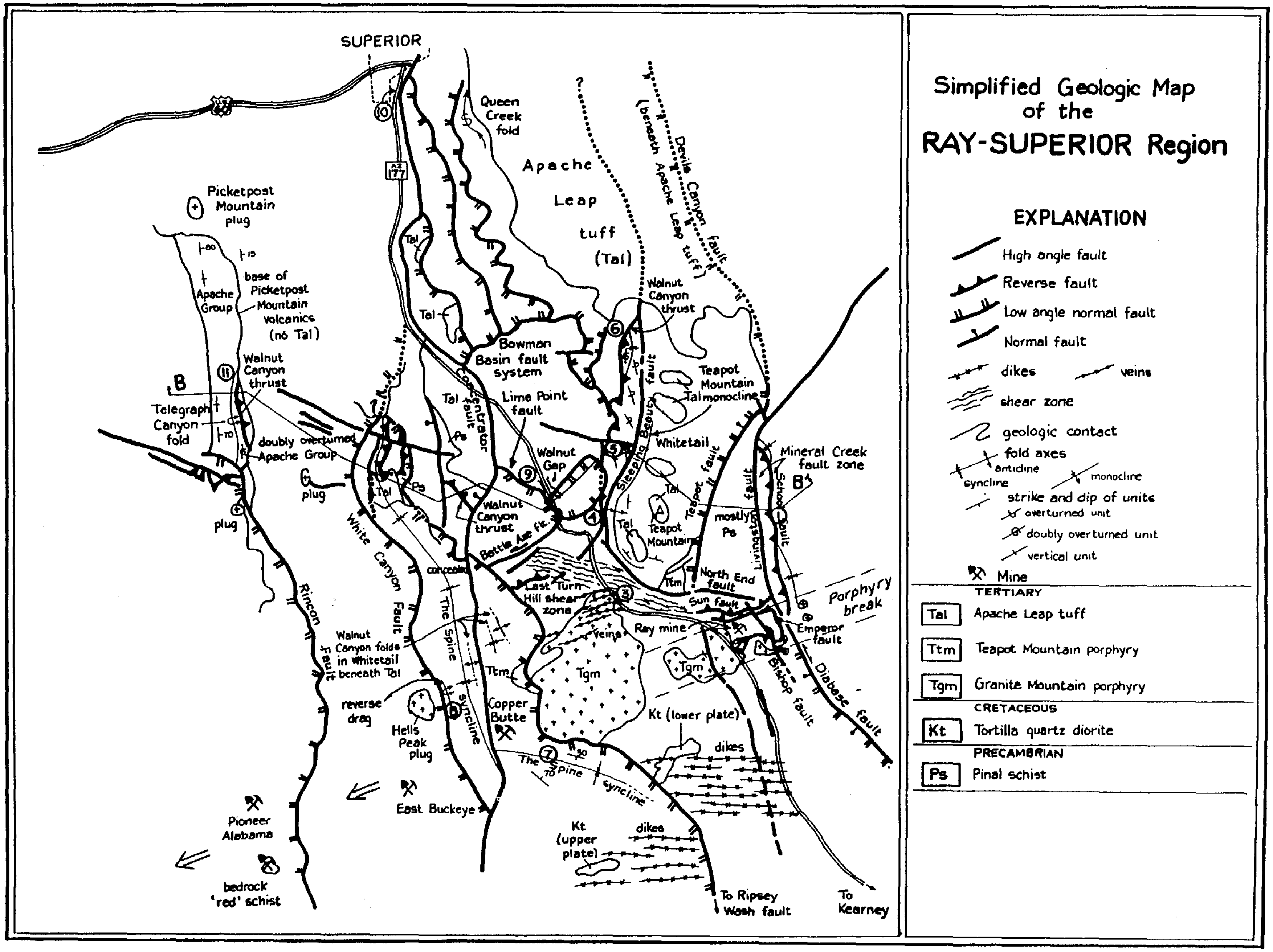


Figure 7. Simplified Geology of the Ray-Superior Region

Notes

At 12 o'clock (east), the massive Apache Leap cliffs of dacite are here and there underlain by patches of Whitetail Conglomerate, with both resting on Pennsylvania Naco Limestone (visible through the Queen Creek gap).

The near sub-skyline ridge is Mississippian Escabrosa Limestone and Devonian Martin Limestone. The reddish cliffs midway down with the mine dump, are Cambrian Bolsa Quartzite, underlying Apache Group, and diabase along the base.

At the base of the hills, the steep west-dipping Concentrator Fault separates the eastern sedimentary units from the volcanic rift units and Quaternary Gila Conglomerate on which we are standing.

The Concentrator Fault extends from the far right, Figure 7, to the left and under the high school, where it splits. One segment curls northwest behind the smokestack and the low hills of Gila Conglomerate, and in front of the Apache Group sediments to the left of the smokestack, and crosses Silver King Wash to the north. The other split (Main Fault) continues north from the high school and goes behind the Apache Group hill before curling northwest to sub-parallel to the Concentrator Fault. They probably join together to the northwest.

Visible behind the smokestack are the smelter and mill remains, and the square sheetmetal cooling tower for the chilled water lines helping to cool off those going underground.

The gap in the main north-south Mississippian ridge behind the smokestack is the location of the Magma fault-vein (trending east-west) and the original No. 1 shaft. The glory hole scar is north of the vein and in Devonian limestone.

The ruffled skyline is Tertiary dacite with narrow strips of Tertiary Whitetail Conglomerate along the base. The 5500-foot elevation Kings Crown Peak, to the northeast, is dacite, but an Earlier Volcanic lies between the dacite and Whitetail there.

The Earlier Volcanics thicken to the north and pinch going south.

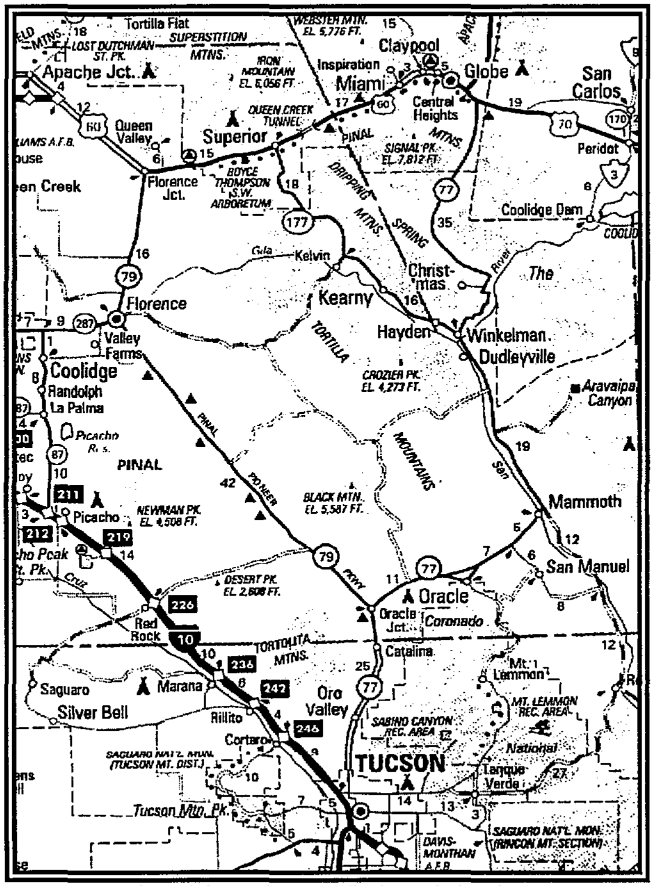
Mile Post	Cumulative Mileage	
		To the north are the perlite processing plants on the Gila Conglomerate and inner rift volcanics. Superior Oil drilled two holes here looking for the Magma Vein, as reported by Ted Eyde in AIME Preprint 73-I-48. They had taken a option from a group lead by Chuck Sewell (personal communications) who had also drilled a few holes earlier.
		Integration of the holes suggest that 5500-7000 feet of down displacement is west of the Concentrator Fault. Dripping Spring Quartzite and diabase were the first pre-mineral units found in most of the holes, but one block had a minor thickness of Mescal Limestone, Bolsa Quartzite, and Martin Limestone, all in an east-dipping homoclinal block, similar to the Paleozoic block east of the Concentrator fault.
		Above the pre-mineral bedrock units is a thick section of rift volcanics and Gila Conglomerate fill. Part of these inner-rift volcanics can be seen to the north in front of the Precambrian schist-metamorphic sequence on the skyline.
		Looking south (3 o'clock) to west, are the inner-rift volcanics with the perlite quarries. Picketpost (Nelson, 1966; Peterson, D.W., 1966) is an intrusive plug of rhyolite and associated units. On the south side of Picketpost, the intrusive came up alongside the vertical dipping Apache Group/Pinal Schist, Figure 7. This fault would be the western fault controlling this inner-rift basin we are standing on.
		On the north side of Picketpost, in Arnett Creek, is a small exposure of a quartz diorite porphyry (Nelson, 1966) which Balla (1972) dated at 71.8 my, and which is similar to the quartz diorite porphyry at Silver King to the north. Balla reports a number of these early Laramide diorites were intruded along the northwesterly "San Pedro hinge zone" extending from far south along the San Pedro and coming up here where this rift-zone is suggested. The zone trends on into the Superstition Mountain Wilderness to the northwest.
		Onward and up on Highway 60 East to the Magma #9 shaft for STOP 2.
225.7	78.7	Outcrop at 9 o'clock at junction has water-lain volcanic debris with fresh water ostracoda.

Mile Post	Cumulative Mileage	
226.0	79.0	Bridge under AZ Highway 177.
226.2	79.2	On right, at east end of offramp, are 6" and 10" water lines. This is the Concentrator Fault zone with Gila Conglomerate on the west and Precambrian diabase-Cambrian Bolsa on the east. **WE'LL STOP AND SEE THE SECTION AFTER LUNCH AT STOP 6.** See STOP NOTES 2 through 6 for information on these stops.
226.4	79.4	In the road cut, reddish Bolsa Quartzite is in contact with bleached replacement textured lower Devonian Martin Limestone units, dipping 30 degrees east.
226.5	79.5	On the right, we zipped by grey-yellow fissle shale at top of Devonian, and the dark middle "C-bed" replacement unit mined at Magma. The underground group will tell us all about the mineralization in this unit at lunch, if we ask.
		Looking quickly to the left (except for the drivers, please) you'll get a glimpse of the old concrete US 60 bridge low over Queen Creek, with the present classic steel arch bridge higher up.
		To the left across Queen Creek, you'll see the band of orange shale separating the Devonian-Mississippian beds as they jut up into the sky.
		On the right, you zipped over the east-west LS&A fault which shows up as the black manganese zone in the Escabrosa Limestone.
226.7	79.7	At the end of the railing on the right is a small parking area for a later time. At road level is the Maroon Shale marker bed. A karst development surface at the top of the Mississippian Escabrosa Limestone. To the east in the Naco Limestone are a few diorite porphyry dikes and pods along bedding.
		On up along the curve prior to the bridge, note the manganese encrusted east-west fault zone, and to the left, the open slices mined for manganese during WWII.
226.9	79.9	Queen Creek Bridge in Escabrosa Limestone.
227.2	80.2	On left, a short piece of Maroon Shale, and into Naco Limestone.

Mile Post	Cumulative Mileage	
227.5	80.5	Road cut in Pennsylvania Naco Limestone. In the afternoon we'll make Stop 5 in this wide area on the right and review the stratigraphy and replacement aspect. Much of this Naco section has numerous thin calcite-filled veinlets subparallel to the Magma Vein, 1,000 feet to the north. Some skarn-looking units, manganiferous, bleached beds, etc.
227.8	80.8	Queen Creek Tunnel-1952. At east end, on left (north), up drainage, is steel cover over Magma's No. 6 shaft. At highway level is major exhaust fan for eastern workings. We are over the A-bed (Devonian) replacement unit lying 2,500 feet below road level.
230.3	83.3	On curve, right side, north dipping fault surface in dacite. Probably part of the Conley Spring fault, or possibly an indication of the Magma Vein.
230.9	83.9	SLOW for turn-off south (right) to Magma Mine Shaft #9, at Stop 2, lunch at Oak Flat, and Stop 3 areas (See Stop Notes).
231.0	84.0	On north, top unit of dacite mass in road cut bank.
231.9	84.9	Going alongside Devils Canyon, and passing over bridge with same name.
232.7	85.7	SLOW. At start of passing lane, take the road right to Asarco's Superior East Project. Last guy in please CLOSE the GATE! Four-wheel drive will be required to continue. See Stop 4 Notes. Members going underground will have Stops 1, 2, lunch, 5, and 6. Members going on surface trip will have all Stops, except no underground visit. Field trip will terminate at the bridge of AZ 177 over US 60 East at Superior at end of Stop 6.

Three choices on return to Tucson:

1) Via AZ 177 to Ray, Winkleman, and Oracle Junction.
   See Addendum Road Log— Superior to Ray;
   then AGS Spring Field Trip, 1994 (John, E., *et al.*, 1994).
2) Via US 60 through Miami, Claypool, and Globe,
   then AZ 77 to Winkleman and Oracle Junction.
   (See Sheridan, *et al.*, 1968, and Peirce, 1967).
3) Back the way you came via Florence Junction.



Map from Arizona Automobile Association © 1986

Safe journey,
and we look forward
to the next outing!

Notes

Addendum Road Log

SUPERIOR to RAY MINE on Arizona Highway 177

Mile Post	Cumulative Mileage	(Note reverse milepost markers.)
167.6	0.0	From Superior Bridge over US 60 East on AZ Highway 177 going south. Gila Conglomerate on downdropped western side of Concentrator Fault.
167.0	0.6	Precambrian Mescal Limestone in roadcut bank.
166.0	1.6	Drill roads to east under dacite are in the Belmont Mine Area.
165.5	2.1	Good view of Picketpost Mountain at 2 o'clock, Weaver's Needle in Superstition Mountain Wilderness at 3:30 o'clock. Road cuts in Gila Conglomerate.
164.0	3.6	On left, next half mile up shallow saddle, Precambrian basalt, quartzite, and diabase, with Mississippian Escabrosa as saddle is approached. On right, inner-rift rhyolite, and tuffs (Creasey, *et al.*, 1983).
163.2	4.4	Saddle area, dacite.
162.6	5.0	Passing over Quaternary gravels and entering Quaternary basalt units with faulted complex to left involving Apache Group quartzite and limestone.
161.9	5.7	Passing over Apache Group units, diabase and quartzites, across fault and onto older Precambrian Madera Diorite basement in valley bottom, then climbing up slope through Apache Group sediments — Pioneer Shale, Dripping Spring Quartzite, diabase, more Dripping Spring, and Mescal Limestone at "Hump" summit.
160.4	7.2	"Hump" Summit. Very complex geology and interpretation. See Wilson, 1952, for early discussion, and Keith, 1985, 1986, for a later discussion of the tectonics of the region. Road on 10% downgrade with major fault on right side, dropping Naco Limestone against Apache Group. Note abundant travertine and brecciated masses; finally

Mile Post	Cumulative Mileage	
		crossing a fault (8.0) and into Pinal Schist on lower curve to Walnut Spring.
159.0	8.6	Crossing bridge at Walnut Canyon.
159.5	9.1	Looking at 3 o'clock (right) down Walnut Canyon to rhyolite plug at Hells Peak. (See Lamb, D.C., in Hammer, D.F., *et al.*, 1962).
159.0	9.6	Summit, stay straight ahead. Road right (3 o'clock) across Laramide quartz monzonite stock (Granite Mountain Porphyry) (some alongside of road) and down to Copper Butte mineralized area. To left are dacite-capped Whitetail Conglomerate knobs.
158.0	10.6	To left, view of Teapot Mountain with dacite capping a thick section of Whitetail Conglomerate resting on Pinal Schist.
157.0	11.6	Various views of the Asarco Ray Complex.
156.0	12.6	On left, road to Visitors View Point.
153.0	15.6	On left, Ray Mine Road. (See John, E., *et al.*, for field guidebook returning to Tucson.)

Stop Notes

STOP 1 — SUPERIOR AIRPORT

This will be our round-up stop after the trip from Tucson. We'll begin again when everyone has arrived.

STOP 2 — MAGMA MINE SHAFT # 9.

See Figure 4.

The Magma staff will give an overview to the group.

The Bootprints article by Paul and Knight (1995) is an excellent up-date of the replacement ores and is reproduced here for your reading. Mr. Kurt Friehauf is presently studying the replacement beds for his Ph.D. at Stanford, and his two recent abstracts follow the Paul and Knight paper.

Replacement Ores in the Magma Mine, Superior, Arizona

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MATTHEW J. KNIGHT *Magma Copper Co., Superior, Arizona*

ABSTRACT

The Magma Mine at Superior, Arizona, has produced over 25 million tons of high grade ore yielding more than 2 billion pounds of copper. Mining prior to 1960 focused on the Magma Vein. Commencing in 1949 mining gradually shifted to carbonate replacement orebodies east of the Magma Vein stopes. The mine currently produces 1,500 tons per day from underground.

Massive copper-iron replacement orebodies in the Magma Mine occur in favorable dolomitic horizons within the Devonian Martin, Mississippian Escabrosa, and Pennsylvanian Naco Formations. The favorable horizons are locally lettered A through E up section from the lower Martin Formation to the lower Naco Formation. The lower Martin A-bed is the most widely mineralized horizon and the lower Escabrosa C-bed is the thickest, most massive horizon.

Replacement bodies consist of chalcopyrite and bornite with hematite, pyrite, quartz, and carbonate gangue. These minerals completely replace dolostones in mantos that extend tongue-like down the dip of the beds as much as 4,400 continuous feet, along the strike of the beds as much as 900 feet, and across stratigraphic thicknesses as great as 150 feet.

The proposed genetic model for these replacement deposits involves premineralization faults that provided hydrothermal fluid channels in underlying silicic rocks and so directed solutions into favorable fault blocks. Ascending solutions then migrated out of these fluid channels up-dip into the overlying carbonate units, favoring horizons with pre-existing permeability. Early replacement of carbonate by hematite and pyrite further enhanced permeability. Subsequent copper-bearing solutions followed established plumbing and replaced early barren iron phases with minerals of progressively higher copper content.

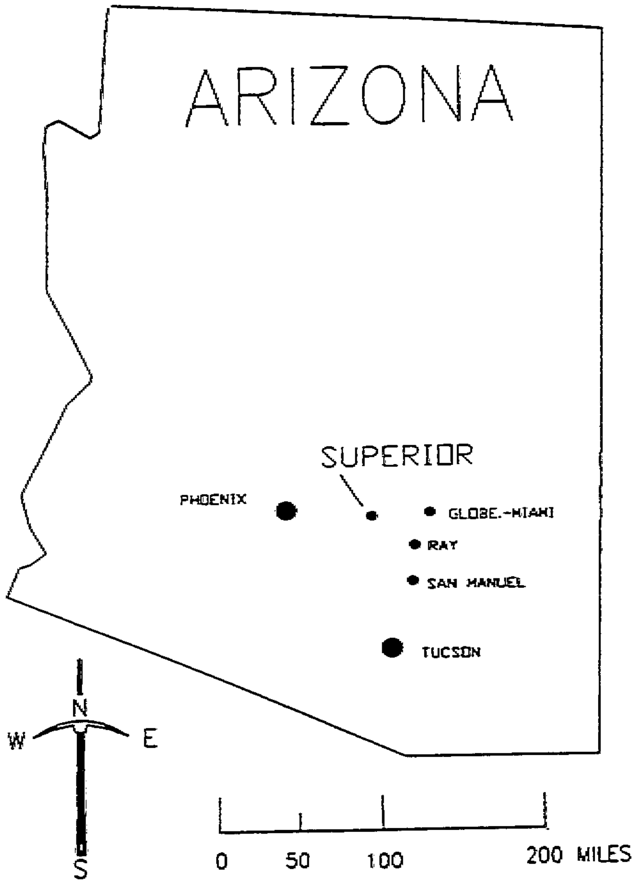

Figure 1. Index map of Arizona showing location of Magma Mine (SUPERIOR).

INTRODUCTION

The Magma Mine is located at Superior, Arizona (fig. 1). The Magma Vein outcrop was discovered in 1875, but the mine's long history of production did not commence until 1911. Brief closures occurred in 1921 to 1923, 1932, and 1982 to 1990. Prior to 1960 most production came from the Magma Vein. Commencing in 1949 production gradually began shifting to the massive replacement ores in carbonate beds that extend at least 14,000 feet east of the Magma Vein discovery outcrop (fig. 4). The continuous high-tenor replacement orebodies are all blind and apex beneath the Apache Leap Tuff.

The 25,800,000 tons of ore produced from the mine to date is about equally divided between vein and replacement orebodies. Hammer (1989) summarized production through 1982 as consisting of 11,300,000 tons of 5.38 percent copper vein ore and 13,600,000 tons of 4.46 percent copper replacement ore. From its reopening in 1990 through 1993 the mine has produced some 924,000 tons grading 5.25 percent copper.

There are several published reports on the geology and mining of the Magma Vein. Gustafson (1961) described the Magma Vein in detail and proposed a spatial, temporal, and geochemical model for its formation. Hammer and Peterson (1968) presented the history, production, and geology of the Magma Mine to 1965; the reader is referred to that paper for descriptions of the surface geology and complete stratigraphic column. Sell (1961) described replacement orebodies in the lower Martin A-bed. This paper focuses on the character of the replacement ores exploited since 1965 and describes geologic relations observed during the course of underground mining.

REPLACEMENT BODY FORM

Replacement orebodies in the Magma Mine are associated with several stratigraphic horizons. Areally restricted but gener-

+ SW Pay Dirt, p. 21A - 3[illegible] employees, 1200 tpd, 100 tpd concentrates.

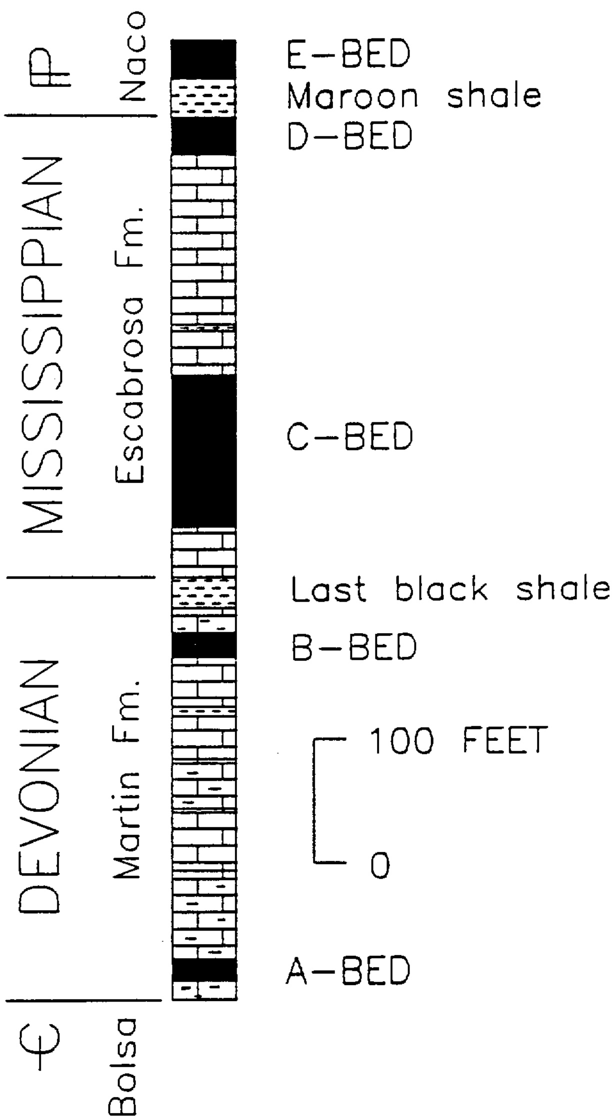

Figure 2. Generalized stratigraphic column of limestone units in the Magma Mine showing position and relative thickness of the A-, B-, C-, D-, and E-beds.

ally high-grade ore occurs in the Precambrian Mescal Limestone (Hammer, 1973). Favorable replacement horizons hosting more continuous orebodies in the Paleozoic carbonate formations overlying the Pinal Schist, Apache Group, and Precambrian diabase intrusions have been given alphabetical designations A through E (fig. 2). Each mineralized horizon has a particular stratigraphic position and distinct characteristics. The East Replacement Mineralized Area (fig. 4) contains the widest range of replaced horizons in the mine.

Massive replacements extend for great distances down the dip of favorable horizons. Replacement ore has been mined from the 2,000 level to the 4,000 level encompassing more than 4,400 feet of dip length and appear to separate into fingers up dip as they apex along east-trending faults. Drilling beneath the down-dip extension of the East Replacement C-bed Orebody indicates an abrupt and blunt termination (fig. 3), but the character of the down-dip termination of other favorable horizons is not as well documented.

Replacement orebodies generally occur as ribbon-like mantos with an easterly orientation. The thickness of individual mantos tends to be consistent, but some notable local variations occur. For example, the A-bed between the 3,000 and 3,200 levels thickens abruptly adjacent to the East Replacement Vein, giving the orebody the appearance of a manta ray in north-south section.

The A-bed replacement horizon near the base of the Martin Formation contains the greatest areal extent of mineral replacement. Five distinct east-trending mantos have been identified in the A-bed extending from the North Boundary Vein to north of the Magma Vein (fig. 4). The massive replacement zones are generally 15 feet thick; thicker sections occur adjacent to feeder veins and ore-control structures. Below the A-bed horizon some 15 to 20 feet of silty limestone overlies the clastic sediments of the Bolsa Formation.

The B-bed is located about 260 feet above the base of the Devonian Martin Formation and is intermittently replaced by massive, fine-grained pyrite in the East Replacement Area. Locally this replacement carries sufficient copper as chalcopyrite to constitute ore. Replacement bodies in the B-bed are restricted to short dip-segments of the upper Martin Formation.

A thinly laminated shaley limestone unit locally designated the "last black shale" delineates the top of the Martin Formation. The C-bed replacement horizon in the lower Escabrosa Formation starts some 30 feet above this shale and is the thickest of any of the replacement horizons, attaining a maximum thickness of 150 feet. Massive replacement in the C-bed extends an average of 300 feet and locally as much as 600 feet northward from the North Boundary Vein. The stratigraphic thickness of the replacement varies over the lateral extent of this orebody.

North of the North Boundary Vein, the C-bed tapers in wing-like fashion similar to that described above for the A-bed. Above the 3,400 level the C-bed Orebody departs from the North Boundary Vein and is centered on the East Replacement Vein. Between the 3,400 and 3,500 levels the C-bed Orebody thickens, forming nearly continuous replacement ore from the base to near the top of the Escabrosa Formation. This upward extension is locally called the C-C bed.

The D-bed occupies the top of the Escabrosa Limestone beneath the overlying "maroon shale." Its thickness is as much as 50 feet. Massive replacement extends through the entire Escabrosa Formation from the top of the "last black shale" into the base of the "maroon shale" marker beds in a few intensely mineralized zones.

The E-bed is approximately 30 feet thick and replaces the first carbonate beds above the maroon shale, the basal unit of the Naco Formation. Alternating limestone and shale units characterize the Naco Formation above the E-bed. Within the area of the mine no units of the Naco Formation above the E-bed are known to be mineralized.

STRUCTURE

There are two major structural elements recognized in the Magma Mine area (Hammer and Peterson, 1968): an east-trend-

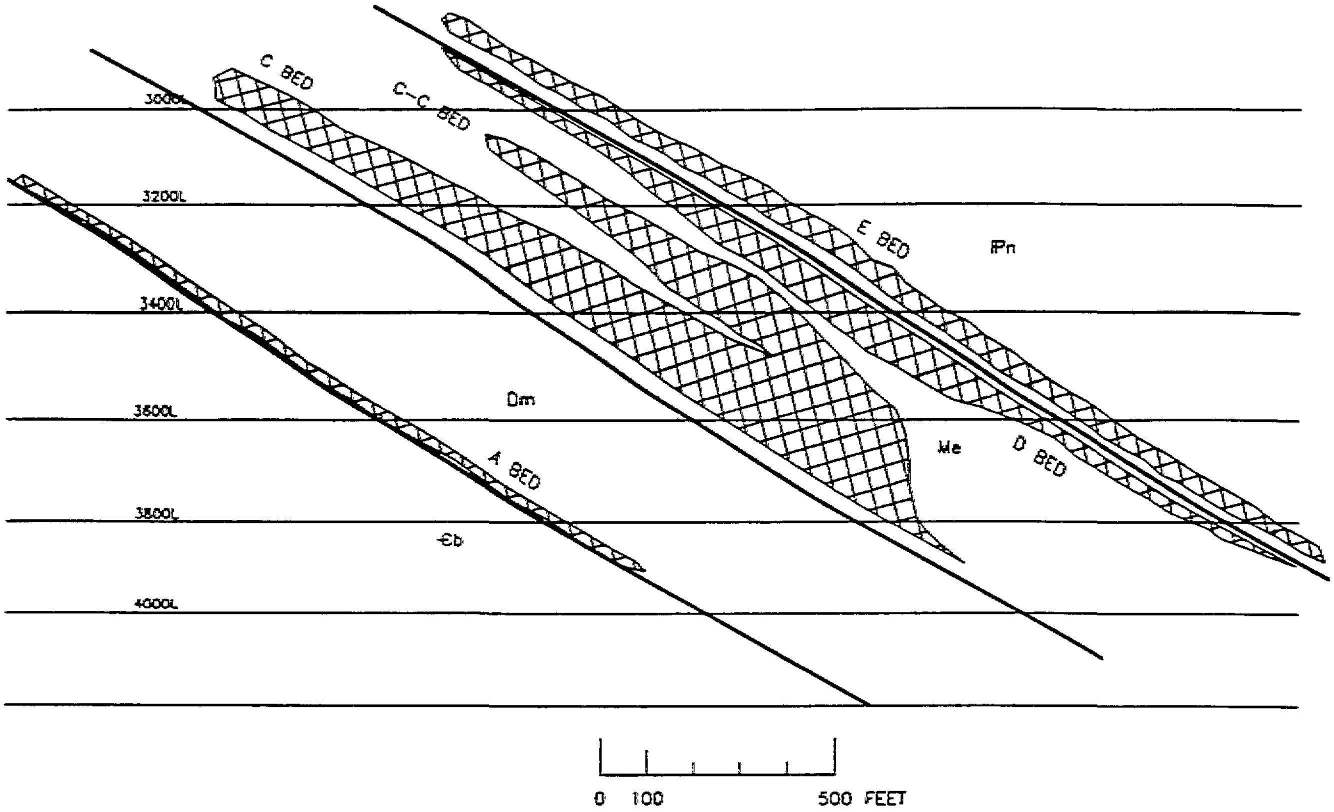

Figure 3. *Generalized east-west cross section through East Replacement Orebodies, showing relative position of ore hosts and variations in replacement thickness. Mine levels are shown in feet below the collar of No. 1 Shaft.*

ing premineralization set of veins and faults and a north-trending set of faults with significant post mineralization movement. The east-trending set is represented principally by the Magma and North Boundary Faults, mineralization along which has created the Magma and North Boundary Veins (fig. 4). In addition, several lesser east-trending faults such as the East Replacement (South Branch) Vein and the South Split of the Magma Vein cut the block of ground between the Magma and North Boundary Faults. Mineralization of these lesser faults has also led to vein formation.

Secondary east-trending faults break the ground between the Magma and North Boundary Veins into several tabular blocks that appear to be offset down to the south in a stair-like fashion. Although the exact direction of slip movement is not known, apparent dip displacement across the Magma Fault ranges from 350 to 450 feet increasing toward the east. For most of the secondary east-trending faults, apparent offset is in the order of 30 to 50 feet. Across the North Boundary Fault minimum apparent dip slip is greater than 2,000 feet.

Segments of the east-trending faults host ore minerals locally but these veins are generally subeconomic. In the vicinity of the replacement orebodies the mineralogy of the east-trending vein set is similar to that of the stoped parts of the Magma Vein, suggesting faults in the area were open during mineralization and acted as feeders for the replacement orebodies.

The north-trending post-ore fault set includes the Concentrator, Main, N-S5W, and numerous unnamed faults that strike north to northwest (fig. 4). This set of faults is characterized by predominantly down-to-the-west apparent movement. Correlative stratigraphic units have been dropped beyond limits reached by mining across the Concentrator Fault, suggesting minimum apparent dip slip of 2,000 feet. The Main Fault exhibits 1,400 feet of apparent left-lateral slip and a similar amount of apparent dip slip; the N-S5W Fault has 400 feet of apparent left lateral slip and 100 feet of apparent dip displacement (Gustafson, 1945).

Faults of the north-trending set are locally mineralized (Hammer, 1994, pers. commun.) but do not constitute ore. They offset both east-west vein and replacement orebodies. Latest movement on the north-trending structures appears to be associated with Basin and Range faulting during Cenozoic time.

The present dip of Paleozoic and older strata is approximately 30° to the east in the west end of the mine; dip flattens somewhat toward the east. Dips as steep as 40° east are, however, observed both at the surface and underground in certain fault-bounded blocks. A 15° angular unconformity exists between the Paleozoic formations in Queen Creek Canyon and the overlying Tertiary ashflow tuff, suggesting that at least half of the present tilt is the result of Cenozoic block-faulting and the remainder is inherited from tilting associated with Mesozoic uplift west of the mine area (Hammer and Peterson, 1968).

CHARACTER OF REPLACEMENT

Mapping has been done on the C, D, and E-beds from the 3,420 level down to the 3,788 level. Mapping shows that there are distinct mineral zones within the orebody that permit classi-

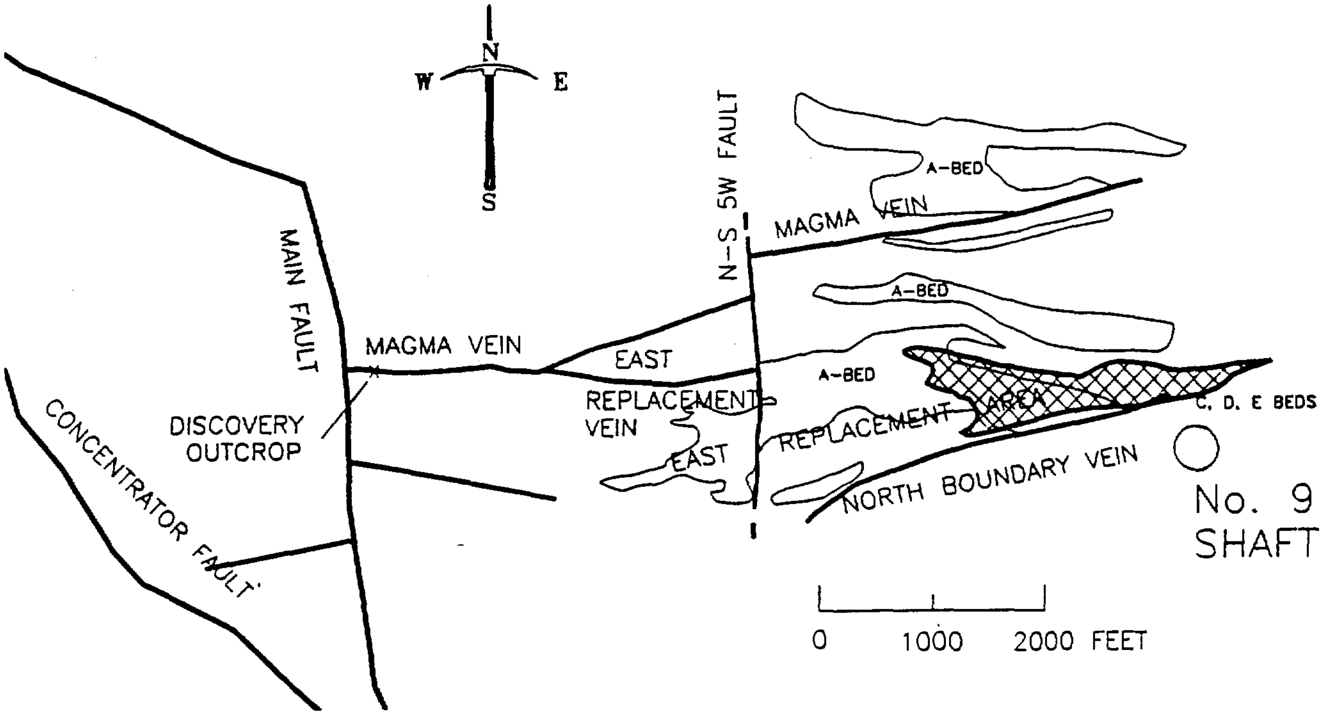

Figure 4. Map of the Superior area showing principal structures, extent of massive limestone replacement, and position of No. 9 mine shaft.

fication into four general mineral types: (1) specularite, (2) pyrite, (3) specularite-pyrite-chalcopyrite, and (4) pyrite-chalcopyrite-bornite. Within favorable horizons, tongues of higher tenor copper mineralization rich in chalcopyrite and bornite extend down dip adjacent to feeder veins, flexures in the beds, ore-control faults, and along replacement fringes. Oreshoots are flanked by lower tenor massive hematite-pyrite-chalcopyrite mineralization. Drilling below the 3,600 level penetrated an A-bed section where a central zone of massive specularite-pyrite-chalcopyrite was encased in coarse-grained dolomite which had replaced the hanging wall and footwall of the horizon. Copper grades depend primarily on the thickness and extent of the hematite-pyrite-chalcopyrite zone.

The ore mineralogy of the massive replacement orebodies is simple, consisting of the copper minerals chalcopyrite and bornite with rare chalcocite and tennantite. The copper minerals are accompanied by minor silica and carbonate gangue and replace and fill open spaces in earlier formed hematite and pyrite. Magnetite is present locally in the A-bed mineralized horizon. Contact relationships between hematite and pyrite bodies and cross-cutting copper-iron sulfide veins indicate hematite is the earliest of the massive replacement minerals and is followed by pyrite. Hematite is present throughout the orebodies but is more dominant up-dip and outward relative to pyrite in the A-bed and is the dominant gangue mineral in areas mined west of the N-S5W Fault (Hammer, 1994, pers. commun.). Hematite is present along the footwall of the bed and along the north fringe of the replaced horizon over the entire dip length of the C-bed Orebody. Hematite generally occurs in large masses of intergrown specularite blades and granular pods, but occurs as a soft red unctuous material wherever it has been stressed by post mineralization faulting, however slight.

Pyrite occurs in large, dense, massive, coarse-grained pods and as small blebs, veinlets, and thin bedding streaks in massive hematite. Pyrite occasionally forms euhedral crystals in a talc rind that surrounds the massive replacements at the limestone contact. Pyrite is commonly replaced by chalcopyrite and bornite. A large massive pod of pyrite at the south edge of the East Replacement C-bed Orebody is unreplaced by copper minerals and consequently nearly barren (less than 1 percent copper).

Chalcopyrite is the primary copper mineral in the replacement orebodies where it occurs as both euhedral octahedrons nested in open spaces between specularite blades and as small pods, thin veinlets, and bedding streaks in massive hematite-pyrite-chalcopyrite ores. Chalcopyrite forms massive pods within larger pyrite pods locally.

Bornite occurs as exsolution blebs within masses of chalcopyrite in high-grade ores and rarely as small granules intergrown between hematite blades and grains. More commonly bornite forms moderate sized tabular, vein-like masses within pyrite-chalcopyrite bodies or at the contacts between hematite and pyrite masses (Friehauf, 1993, oral commun.). In the East Replacement C-bed Orebody there are two root-like masses with a high proportion of bornite that extend down the dip of the beds.

Silica is present in the replacement ores but is volumetrically small compared with the massive hematite and the sulfide minerals. Chalcedonic quartz is common in the distal up-dip portions of the replacements that crop out. Chalcedony occurs rarely as isolated masses filling intergranular spaces in hematite and pyrite in the deeper parts of massive orebodies. Crystalline quartz commonly occurs with bornite veins and as vug fillings in massive pyrite.

Carbonate minerals are present as a gangue constituent of the massive replacements. Calcite occurs in coarse late stage crystals that fill intergranular spaces and vugs in massive hematite and pyrite. Ankerite and dolomite are also common as isolated intergranular masses. Granular recrystallized dolomite forms a thin hanging wall and footwall sheath encasing massive hematite-pyrite-chalcopyrite that replaces the center of the A-bed below 3,600 level.

Sphalerite and galena are rare within the massive replacements but do occur in sparse, thin veinlets and bedding streaks near the fringes of massive replacements. Microscopic grains of sphalerite fill open space in porous recrystallized dolostone along strike for a few feet beyond the limit of massive replacement in favorable horizons. Below 3,700 level considerable sphalerite is present in the hanging wall of the C-bed Orebody. Honey-brown crystalline barite has been reported (Hammer and Peterson, 1968) from large cavities at the up-dip terminations of some of the A-bed orebodies but is unknown in the deeper replacement orebodies.

Mapping is most detailed in the C-bed, where mining has focused since 1990. Massive specularite typically occurs on the northern and northwestern fringes of the C-bed Orebody near the limit of replacement (fig. 5); this phase carries less than 1 percent copper. Massive pyrite which also carries less than 1

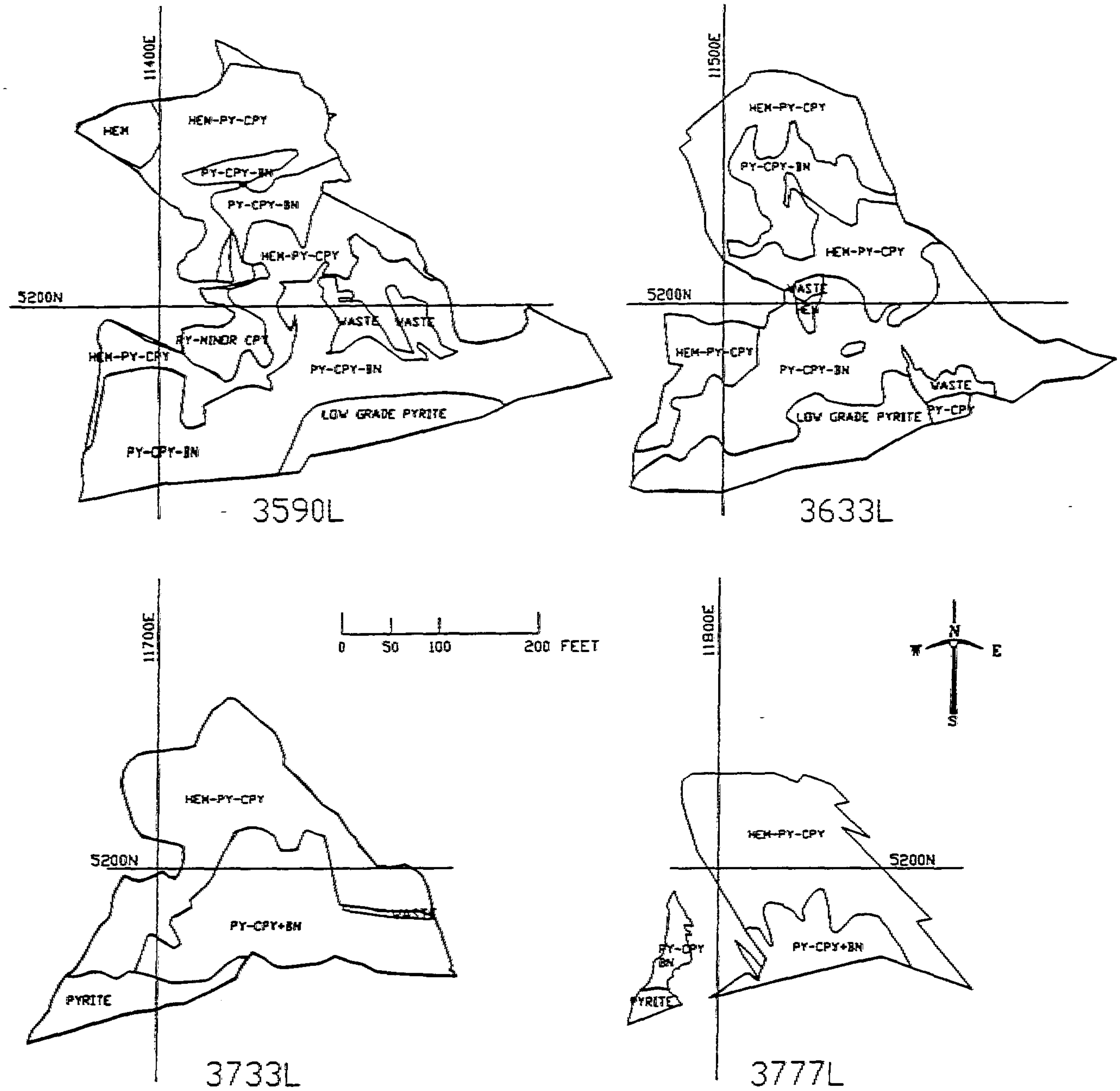

Figure 5. Horizontal slices through the East Replacement C-bed Orebody showing distribution of replacement mineral types. Waste refers to unreplaced carbonate pods within the orebody. Coordinate lines are Magma Mine survey system.

percent copper occurs only as a lens on the southern end of the C-bed Orebody from approximately the 3,570 level down to near the 3,800 level near the North Boundary Fault.

Specularite-pyrite-chalcopyrite ore typically consists of massive granular to bladed specularite with 10 to 30 percent pyrite-chalcopyrite. This type of ore is often quite porous and rarely has vugs which contain well crystallized specularite; copper grades range from 3 to 8 percent. Limited historical data suggest that the orebody above the 3,400 level consisted mainly of specularite-pyrite-chalcopyrite ore with occasional pods of high-grade pyrite-chalcopyrite-bornite ore. Below the 3,400 level the specularite-pyrite-chalcopyrite assemblage tends to occupy the northern portions of the orebody, while the pyrite-chalcopyrite-bornite assemblage dominates in the south. The specularite-pyrite-chalcopyrite assemblage persists to the termination of the orebody below the 3,800 level (fig. 5).

The pyrite-chalcopyrite-bornite assemblage comprises the high-grade roots mentioned earlier. Major bodies of these copper sulfide minerals persist from the 3,460 level to the downward termination of the C-bed Orebody. This copper sulfide phase is usually strongest in the southern portions of the orebody with a weaker root in the north central portion. Grades in the pyrite-chalcopyrite-bornite ore are typically quite high ranging from 5 percent to more than 20 percent copper. Rare large lenses of chalcopyrite-bornite yield stope sample grades over 25 percent copper.

Within the C-bed Orebody replacement of host rock is virtually complete but there are occasional horsts of unreplaced carbonate within the ore (fig. 5). These horsts may be limestone or dolomite and typically show little evidence of replacement. Commonly these blocks have haloes of very high-grade pyrite-chalcopyrite-bornite ore surrounding them. Replacement contacts are quite sharp with virtually no gradation from massive replacement to unreplaced limestone or dolomite.

Vein/fault structures within the C-bed Orebody are difficult to recognize, but there do seem to be persistent breccia zones crossing from west to east. These breccia zones likely correlate with the horst bounding faults that form the "notch" on the west side of the C-bed (fig. 5).

The mixed hematite-pyrite-chalcopyrite ore type is characteristic of the D-bed. Numerous high-grade pyrite-chalcopyrite-bornite pods are present, but they are smaller and more irregular than those of the C-bed.

The E-bed is generally replaced by mixed hematite-pyrite-chalcopyrite material. High-grade pyrite-chalcopyrite-bornite pods are less common than in the D-bed, thus the E-bed has a lower overall grade. Contacts between replaced beds and unmineralized sedimentary rocks are very sharp in the E-bed as in the other mantos. Replacement also appears to be more closely controlled by bedding in the D-bed, with the different mineral types appearing as ribbons parallel to beds rather than as large pods such as are seen in the C-bed.

ALTERATION

Alteration of carbonate wallrocks surrounding replacement orebodies consists of inconspicuous dolomitization and talc formation. The relation between wallrock alteration and replacement bodies is not well known.

Certain primary dolostones and non-magnesian limestones in the carbonate section have been recrystallized and affected by magnesian metasomatism (Hammer, 1994, pers. commun.) to form favorable replacement horizons. These recrystallized rocks are characterized by a dark- to light-gray color, megascopically fine-grained texture, and vitreous luster.

Spherical and ovoid masses of white crystalline calcite a few inches across are locally present in the gray dolostones of the C-bed. These calcite balls are rimmed with talc within approximately 100 feet of the massive replacement bodies. Closer to massive replacement bodies white talc replaces spherical, ovoid, and lens-like spots within host carbonates. Talc alteration is intense in the interval between the C and D horizons.

GENETIC MODEL

Formation of replacement orebodies at Superior followed development of the east-trending fault system. A stair step down-to-the-south pattern of fault-bounded blocks developed in a north-south tensional environment. Some of the tensional structures filled with intrusive dike material prior to mineralization.

Host sedimentary units dipped gently to the east at the time of mineralization. The broad distribution of mineralized and altered rock in and along the east-west veins and faults indicates

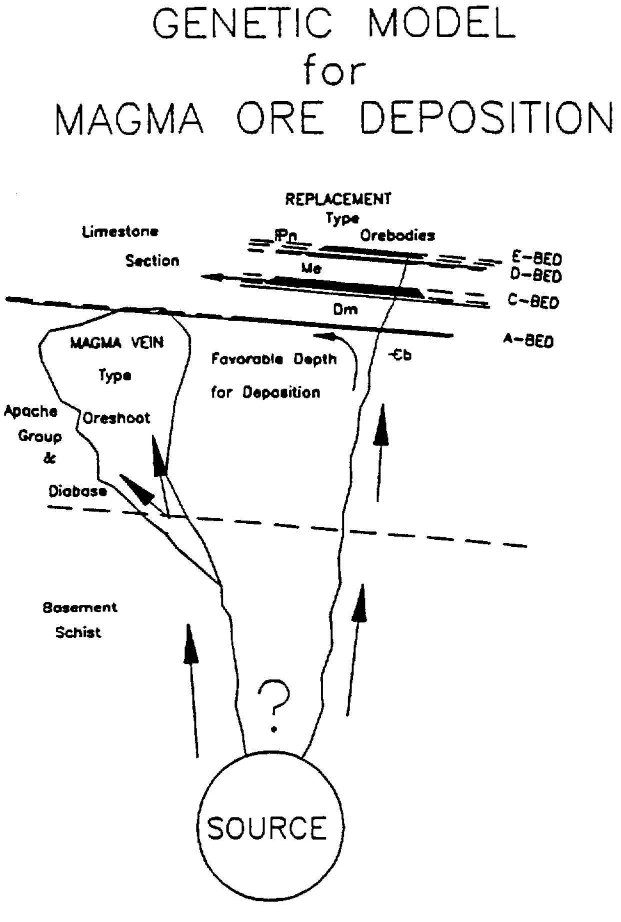

Figure 6. Schematic diagram of hydrothermal system which produced vein and replacement orebodies in the Magma Mine.

that source solutions ascended from a deep level affecting a wide area and that plumbing features played an important role in localizing orebodies. Some intersections and deflections were open and enhanced rock permeability, while other structural bearing surfaces and specific rock types impeded solution flow.

Mineralizing solutions ascended from depth through a thick sequence of siliceous rocks. That schists of the Pinal Formation, siliceous sediments of the Apache Group, and thick diabase sills all supported open fractures sufficiently to allow mineralizing solutions to ascend to moderate depths is indicated by the mesothermal character of the vein and replacement ores. Oreshoots developed along faults to form veins where physical conditions of temperature and pressure were favorable and enclosing wallrocks were siliceous (Hammer and Peterson, 1968).

Some porous beds within the carbonate sequence above the siliceous rocks were less restrictive to upward fluid flow than the feeding faults. Recrystallization of certain dolomitic horizons further enhanced permeability, and dissolution of the host rocks increased porosity and directed even greater amounts of fluid into favorable hosts once flow was established.

Access to higher carbonate beds was established through specific plumbing channels at favorable intersections and deflections. Intersections of the east-trending veins and faults with major east-northeast-trending veins and faults appear to have been particularly strong channelways.

Metallic mineral deposition commenced with replacement of recrystallized dolostone by massive bodies of intergrown bladed specularite crystals and porous granular hematite aggregates. Porosity within these hematite bodies was high, allowing solutions to continue to pass through in great volumes.

As ore formation continued, earlier-formed hematite was replaced by pyrite, often along relict bedding planes. Solutions may have spent their sulfur while ascending: The deposit is crudely zoned, with hematite dominant up dip and sulfide minerals more common down dip.

Early pyrite was subsequently replaced by chalcopyrite. Where greater volumes of solution ascended through distinctly established channels, further copper enrichment led to formation of the bornite-rich "roots," pods, and veins.

The near total replacement of host rocks within the orebodies make original structures within the orebodies difficult to observe. Features such as the high grade "roots" in the C-bed and abnormal thickening of the A-bed to a manta ray-like form may indicate intersections of steep vein-like structures with favorable beds. Commonly such ore features align with faint fractures and veins in unmineralized limestone. Breccia zones within the massive sulfide replacement of the C-bed appear to be associated with east-trending structures.

Solutions made very little penetration into the surrounding limestone country rock beyond the limits of the orebodies resulting in only narrow alteration envelopes of talc, sphalerite, and rare galena.

The top portion of the Magma Vein and the up-dip portion of some of the replacement orebodies have been exposed to oxidation near a paleosurface. Mine records suggest the occurrence of oxidation and supergene enrichment in the vein deposits. Oxidation was recorded in some of the upper levels of the replacement orebodies, but enrichment of replacement ores is less well documented and some chalcocite in upper levels may be supergene.

The mineralized area was covered by a thick sequence of fluvial sediments and an ashflow tuff unit prior to being faulted and tilted by north- to northwest-trending basin-and-range faults. Only a short segment of the Magma Vein has been exposed by erosion, and this outcrop led to discovery of the system. All of the continuous massive replacement orebodies are blind, apexing deep beneath the postmineralization cover.

ACKNOWLEDGMENTS

The authors would like to thank Magma Copper Company for its support in producing this paper and allowing it to be published. Don Hammer has contributed to developing the geologic concepts presented here and shared his historical knowledge of the district, and Kurt Friehauf has shared his recent observations and thoughts about the geology of the replacement orebodies.

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Carbonate-replacement Cu-(Au) deposits associated with a high-sulfidation state Butte-type vein system, Superior District, AZ

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Copper veins in the Superior district closely resemble quartz monzonite-hosted "Main stage veins" at Butte (MT), Tintic (UT), Yauricocha (Peru), and Chuquicamata (Chile) in vein filling mineralogy and associated alteration. Carbonate-hosted ores in the Superior district are similar to the carbonate-hosted ores of Bisbee (AZ) and Yauricocha (Peru). The association of Butte, Yauricocha, Chuquicamata, and Bisbee with porphyry copper systems suggests Superior is related to an as-yet undiscovered porphyry copper system.

East-dipping Paleozoic carbonates host the stratabound massive specularite-copper sulfide and Pb-Zn sulfide replacement ("manto") ores where E-W-striking, enargite-bearing veins (e.g. Magma vein) intersect favorable carbonate strata. Favorable strata occur near the base of the Devonian Martin Formation (5 m thick "A-bed" dolostone), the lower part of the Mississippian Escabrosa Limestone (< 60 m thick dolomitic and calcitic "C-bed"), and below and above the shale at the base of the Pennsylvanian Naco Limestone (5 m thick "D-" and E-bed"). "Nonfavorable" limestone and dolostone beds that lie between the favorable horizons show little visible evidence of fluid-rock interaction more than a meter from the feeder veins.

Footwall contacts of mantos are locally discordant (on the order of a meter), but hanging wall contacts are discordant by up to tens of meters. Portions of mantos tend to be either specularite- or sulfide-dominant with sharp (< 25 cm) contacts between zones. Early replacement of carbonates by massive specular hematite with 5-15% disseminated pyrite and chalcopyrite was followed by the formation of massive pyrite-chalcopyrite ± bornite replacement veins and mantos *within* the specularite body. The time-integrated mineral association zoning is from central bornite+chalcopyrite+pyrite+quartz outward to pyrite-chalcopyrite-quartz to specularite+pyrite+chalcopyrite. Small, isolated massive galena-sphalerite-pyrite-quartz pods within limestones/dolostones occur peripheral to copper orebodies.

Wall-rock alteration adjacent to specularite-copper sulfide mantos is characterized by mm-scale white dolomite or calcite veinlets ± quartz-specularite veinlets with bleached halos within meters of the contact. At one locality, a latite porphyry dike in contact with a manto is pervasively altered to sericite-pyrite and chlorite and is cut by quartz-sericite-pyrite, specularite, and quartz-adularia ± chlorite veins. XRD analyses of siliceous sulfide breccias in the central zone of the C-bed orebody indicate the presence of dickite and zunyite -- minerals typical of hypogene advanced argillic alteration in quartzofeldspathic rocks in other Butte-type systems -- suggesting manto ores at Superior represent the carbonate-hosted analogues of advanced argillic alteration.

Skarn and Cu-(Au)-rich massive sulfide/specularite carbonate-replacement deposits of the Superior District, AZ

Kurt C. Friehauf, Dept. of Geological and Environmental Sciences, Stanford University, Stanford CA 94305-2115

The presence of pre-mineral porphyry dikes, skarn followed by high-sulfidation, enargite-bearing Cu-Au veins and pebble breccias suggest the manto ores of the Superior district are similar to the carbonate-hosted ores of Tintic (UT), Bisbee (AZ), Yauricocha (Peru), Morococha (Peru), and Cananea (Sonora) and the carbonate-hosted analogues of high-sulfidation base metal lode veins such as at Butte (MT), Bor (Yugoslavia), Recsk (Hungary), Srednegorje (Bulgaria), Chuquicamata (Chile), Lepanto (Philippines), and Nena (Papua New Guinea).

East-dipping Paleozoic carbonates in the Superior District (26 Mt 4.7% Cu, 1 ppm Au, 45 ppm Ag, Matt Knight, Pers. Comm., 1994)) host garnet, amphibole, and talc skarn and stratabound massive specularite-copper sulfide and Pb-Zn sulfide replacement ("manto") ores where E-W-striking, enargite-bearing veins (e.g. Magma vein) intersect favorable carbonate lithologies. Favorable strata occur near the base of the Devonian Martin Formation (5 m thick "A-bed" dolostone), the lower part of the Mississippian Escabrosa Limestone (< 60 m thick dolomitic and calcitic "C-bed"), and below and above the shale at the base of the Pennsylvanian Naco Limestone (5 m thick "D-" and E-bed"). Hydrothermal fluids did not react visibly with "non-favorable" carbonate strata.

Garnet-amphibole-pyrite-(sphalerite) skarn, followed by rhythmically-layered sphalerite-magnetite-talc bodies, pre-date specularite-copper sulfide manto formation. Garnet-bearing skarn occurs predominantly as east-striking veins (i.e. the same fracture set occupied by copper ores and pre-mineral porphyry dikes) with small mantos flaring out in favorable members of the "D-bed". Amphibole-bearing skarn consists of an early, forest green, fine-grained (2-3 mm grains) variety growing on and cutting compositionally-zoned garnet grains which is in turn cut by light green coarse-grained (10-15 mm) amphibole veins. No copper minerals precipitated during skarn formation. Garnet is weakly altered to soft, tan-colored clay and locally specularite where cut by pyrite-bornite ± specularite-calcite veinlets. Skarn amphiboles have been altered to talc. Rhythmically-banded talc-magnetite skarn replaces dolomitic units and locally contains talc-altered coarse-grained amphibole veins.

Massive galena-pyrite-sphalerite-quartz mantos (< 1m thick) and replacement veins lacking associated talc alteration occur as separate bodies from the main specularite-copper-sulfide mantos. No magnetite or specularite and only traces of chalcopyrite precipitated with galena-bearing massive sulfide. Sphalerite displays chalcopyrite disease and pyrite is locally platy (a la Leadville, CO).

Massive specularite-sulfide mantos (5-60 m thick, < 90 m wide, and < 300 m down the dip) post-date skarn and consist of coarse-grained specular hematite, pyrite, chalcopyrite, bornite, minor chalcocite, and < 5% quartz. Rock types tend to be either specularite- or sulfide-dominant (>80:<20) with sharp (< 25 cm) chalcopyrite-rich contacts between types. Sulfide-dominant (2-4 mm granular pyrite-chalcopyrite (85:15) ± bornite) bodies occur as coalescing elongate pods (typically 6-25 m) within a "sea" of specularite-dominant (80-95% 1-5 mm specularite + 5-10% 2-5 mm pyrite + <10% chalcopyrite) rock that generally extends to the sharp (<10 cm wide) contact with wall-rock carbonate. Specularite-dominant rock predominates in shallower levels, along the footwall, and along the northern margin of the manto, but sulfide pods predominate at intermediate levels. WNW-elongate sulfide pods (i.e. similar orientation to veins in the district) widen at some stratigraphic levels within the specularite-dominant zone of the C-bed orebody, possibly reflecting stratigraphic control on a late sulfidizing fluid flow into favorable replacement horizons within earlier specularite. NW and NNE-striking, irregular bornite-chalcopyrite and bornite-pyrite replacement veins and bornite-matrix pyrite-bornite- + pyrite-chalcopyrite-fragment breccias are the locus of high-grade Cu-Au ore within the sulfide pods. Bornite veins commonly have rhythmically-banded bornite-pyrite or nebulous bornite-chalcopyrite/chalcopyrite-pyrite selvages. Paragenetic relations suggest an early stage of specularite + minor pyrite-chalcopyrite replacement of carbonate followed by formation of sulfide-dominant zones by sulfidation of specularite to replacement veins and masses of pyrite, chalcopyrite and bornite. Even, nearly continuous 0.1 - 0.5 cm specular hematite rinds on small (<30 cm thick) massive pyrite >> chalcopyrite mantos in limestone, suggest specularite also precipitated as a peripheral mineral zone during introduction of Cu-Fe sulfides.

Wall-rock alteration peripheral to specularite-copper sulfide mantos is characterized by mm-scale white dolomite or calcite veinlets ± specularite veinlets with bleached halos, and white talc spots (2-40 mm diam.) in dolomite within meters of the contact. Small (< 1 m) pyrite-chalcopyrite mantos do not visibly alter limestone. A 20-foot thick, quartz-eye-poor, hornblende-rich "latite" porphyry dike, where cut by massive sulfide/specularite mantos, is pervasively altered to sericite-pyrite and chlorite and cut by quartz-sericite-pyrite, specularite, and quartz-adularia ± chlorite veins. Hornblende sites were locally replaced by specularite.

STOP 3 — OVERLOOK TO DRILL HOLE A-4

On Figure 8, Stop 3 is near the "T" in the word "**OAK FLAT**" near Devils Canyon.

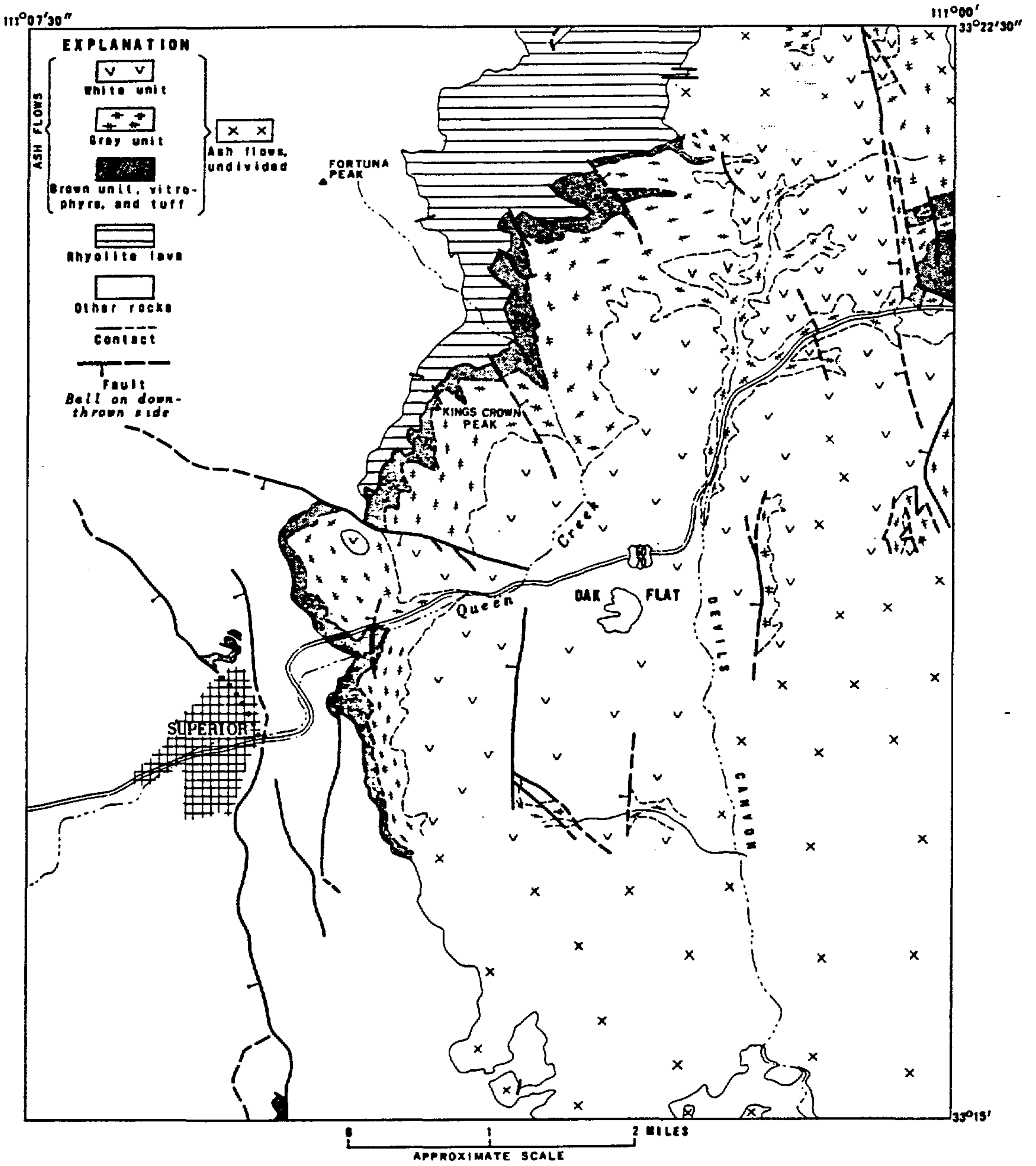


Figure 3 – Generalized geologic map of the Superior quadrangle, showing the distribution of recognized field units within the ash flow sheet. Recognition of the units has permitted identification of several faults within the sheet.

Figure 8. (adapted from Peterson, D.W., 1968)

The hole A-4 was a 1971 penetration and was rotary drilled to 3,593 feet, then cored to completion at 6664 feet (Sell, 1995). Probably a slim-hole record at the time.

The dacite is 1,975 feet thick with an additional 158 feet of Earlier Volcanics.

A very thick sequence of Whitetail Conglomerate was rotaried and cored, 4,206 feet worth, before a slide block of 109 feet of Escabrosa Limestone was encountered. A 36-foot section of Whitetail underlies the Escabrosa slide block and confirms its moved aspect. More Escabrosa, 87 feet, was boxed, at which point a steeply dipping fault was cut. This fault is undoubtedly the Devils Canyon Fault. Under the fault, Pinal Schist is intruded by a dark porphyry (biotite quartz monzonite), both of which had traces of pyrite, chalcopyrite, and moly. A K-Ar date of 62.6 my was returned on this intrusive.

A piece of the Devils Canyon Fault was mapped by Don Peterson, 1968, Figure 8, bringing the gray unit of dacite against the white unit, on the east side of Devils Canyon.

Asarco drilling on both sides of the canyon indicates 500-600 feet of west-side-down displacement of the Earlier Volcanic base across the Devils Canyon Fault. The increased thickness of Whitetail across the fault here is around 1,400 feet. As no Paleozoics exist east of the Devils Canyon Fault under the dacite, the entire Precambrian sedimentary section, the diabase, and the Paleozoics must have been stripped off, plus an unknown amount of Pinal Schist. This amounts to 6,800 feet of section at Magma. If the Escabrosa is near the base, as in drill hole A-4, this suggests a minimum of 5,200 feet of displacement from schist to schist across the Devils Canyon Fault.

At Ray to the south, the Diabase Fault separates Precambrian on the east from schist on the west, and a minimum of 2,000 feet of displacement has been suggested (Fountain, 1981; Cornwall, *et al.*, 1971).

Aerial photos suggest the fault continues west of the Pinto Valley Mine and is lost in the vicinity of Roosevelt Lake. Displacement probably decreases in offset to the north, however, no good marker beds are available for control.

The plus-5,000 feet of displacement along part of the Devils Canyon Fault is similar to the 5,500-7,000 feet of displacement on the Concentrator Fault at Superior, and suggests the Devils Canyon Fault is a "failed rift" split from the main rift to the south. The homoclinal result and sag in the area of drill hole A-4 resulted in the thick deposition of Whitetail Conglomerate. It is the thickest known section of Whitetail in the region.

Figure 9 is a plan map showing the known drill holes on the Plateau (Sell, 1995).

We'll now return to US 60 East and continue the road log to the gate to Superior East.

STOP 4

Four wheel-drive will be required to continue off the AZ 60 East. Last guy, please CLOSE the GATE!

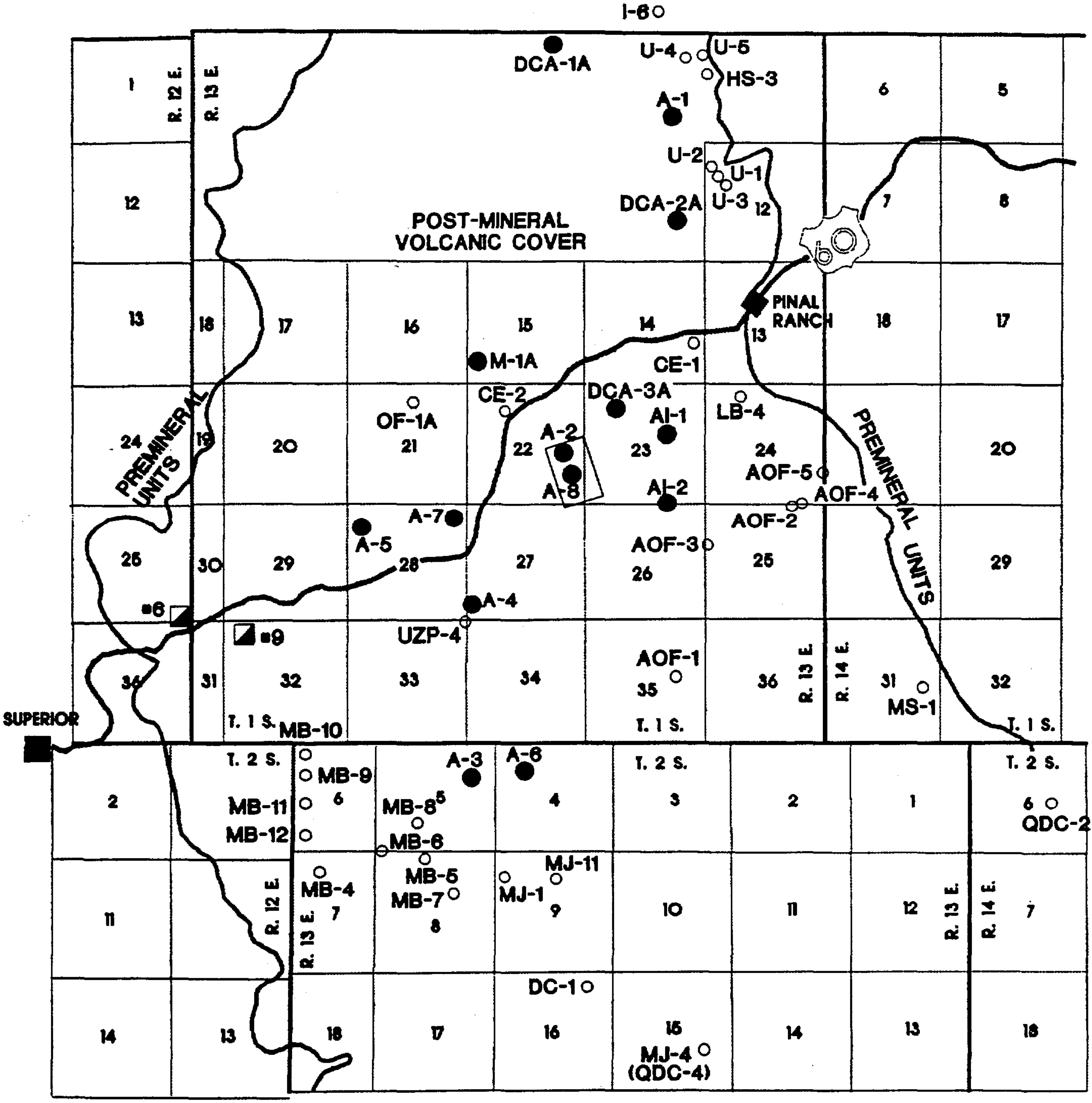


Figure 9. (adapted from Sell, 1995)

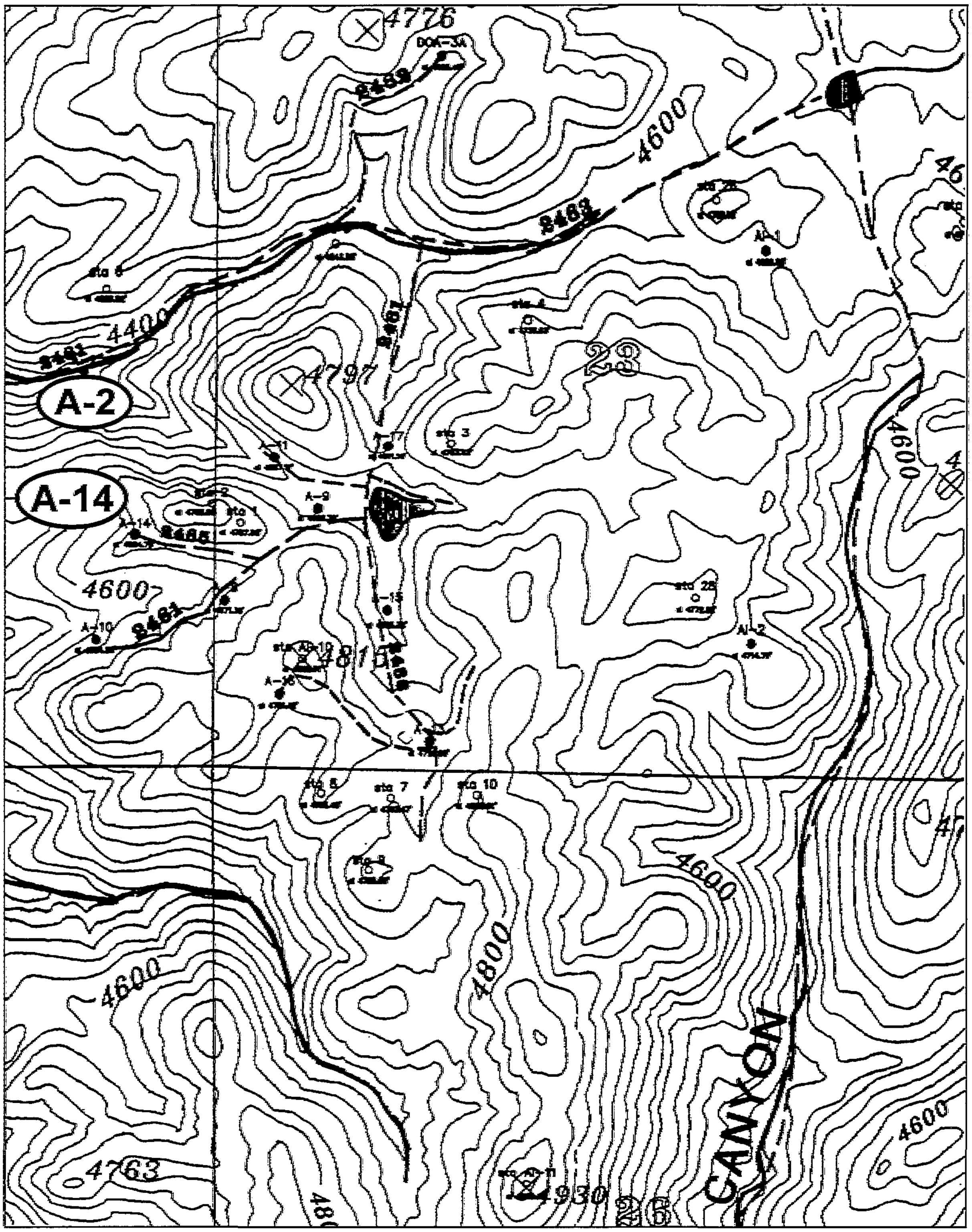


Figure 10. Drill hole detail at Superior East project.

We will go by hole A-2, then on up to the parking area at the big pond (about 1½ miles) and then walk on up to hole A-14 for an overview of the Superior East project. The abstract and exploration concept is reprinted here from the Bootprints article by Sell, 1995.

Discovery of a Deep (3500 feet) Unexposed Porphyry Copper Deposit at Superior East, Pinal County, Arizona

JAMES D. SELL *ASARCO Incorporated, Tucson, Arizona*

ABSTRACT

In 1970 ASARCO Incorporated initiated a search for porphyry copper mineralization postulated to lie under post-mineralization rocks between Superior and Miami in Pinal County, Arizona. An early drill hole penetrated 2,133 feet of volcanics and 4,351 feet of conglomerate for a total of 6,484 feet of post-mineralization cover rocks. Below the cover rocks the drill hole intercepted Laramide biotite quartz monzonite intruding Precambrian Pinal Schist which contained trace amounts of copper and molybdenum and displayed alteration and mineralization characteristic of porphyry copper deposits. Four drill holes later, the "discovery" hole penetrated 3,226 feet of post-mineralization rocks before intercepting the leached capping of a porphyry system. Below the leached capping, 646 feet of core assayed 1.57 percent copper. The intercept also averaged 31 ppm molybdenum, 0.22 ounces per ton silver, and trace gold.

Sulfide minerals at Superior East are chalcocite, bornite, chalcopyrite, and minor pyrite. Mineralization is disseminated and vein-controlled within Precambrian Pinal Schist intruded by several Laramide porphyries. Drilling in the deposit suggests a minimum geologic resource of 200 million tons with a grade of 0.90 percent copper including a high-grade core of 100 million tons at 1.1 percent copper.

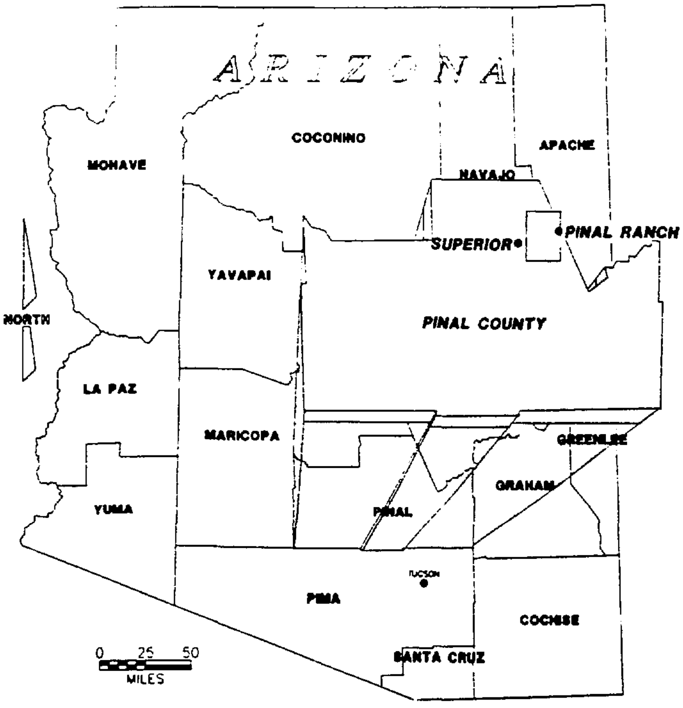


Figure 1. Location of Superior East Project, eastern Pinal County, Arizona

INTRODUCTION

The Superior East Project is located between Superior and Pinal Ranch west of Miami in eastern Pinal County, Arizona (fig. 1). U.S. Highway 60 bisects the area from east to west; Devils Canyon bisects the area from north to south.

The initial report (Sell, 1970) proposing exploration for a major porphyry copper deposit hidden beneath volcanic cover rocks between Superior and Pinal Ranch was accepted by ASARCO International's New York corporate office, and an initial appropriation of funds was advanced in 1970.

EXPLORATION CONCEPT

Mineral exploration trend

N.P. Peterson (1962) summarized the geology of the Globe-Miami-Superior Mineral Belt, a six-mile wide, thirty-mile long northeast-trending mineralized zone (fig. 2). He noted that nearly half the area between the Old Dominion Mine (Globe) to the northeast and the Magma Mine (Superior) to the southwest is covered by thick blankets of post-mineralization volcanics and basin-fill deposits.

Following Mayo (1958), Balla (1972) labeled the northeast-trending zone from Globe to Magma the Jemez Zone and noted that intrusive activity along this trend was evident at 1,420 Ma with renewed activity at 840 Ma. Between 70 Ma and 60 Ma a number of intrusives including the Schultze Granite dated from 62 to 58 Ma were emplaced along the zone. Intrusive activity resumed at 20 Ma with the emplacement of the Wood Camp Canyon Quartz Monzonite north of Superior.

The intrusive and structural histories of the region are summarized by Billingsley and Locke (1941), Gay (1972), Graybeal (1972), Hammer and Peterson (1968), Landwehr (1967), Lindgren

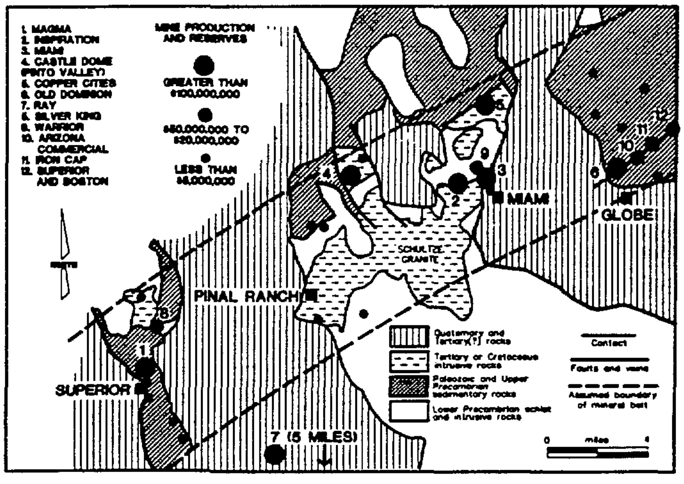
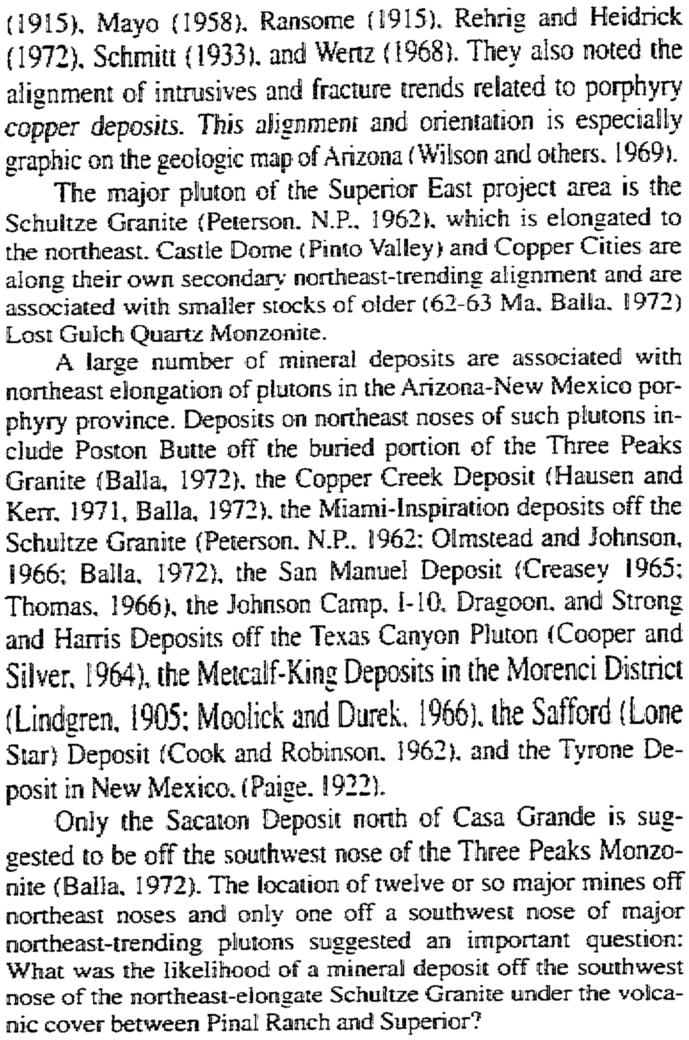


Figure 2. Index map of Pioneer (Superior) and Miami-Globe Districts with indicated limit of mineral belt and location of productive deposits (modified from N.P. Peterson, 1962).



> (1915), Mayo (1958), Ransome (1915), Rehrig and Heidrick (1972), Schmitt (1933), and Wertz (1968). They also noted the alignment of intrusives and fracture trends related to porphyry copper deposits. This alignment and orientation is especially graphic on the geologic map of Arizona (Wilson and others, 1969).
>
> The major pluton of the Superior East project area is the Schultze Granite (Peterson, N.P., 1962), which is elongated to the northeast. Castle Dome (Pinto Valley) and Copper Cities are along their own secondary northeast-trending alignment and are associated with smaller stocks of older (62-63 Ma, Balla, 1972) Lost Gulch Quartz Monzonite.
>
> A large number of mineral deposits are associated with northeast elongation of plutons in the Arizona-New Mexico porphyry province. Deposits on northeast noses of such plutons include Poston Butte off the buried portion of the Three Peaks Granite (Balla, 1972), the Copper Creek Deposit (Hausen and Kerr, 1971, Balla, 1972), the Miami-Inspiration deposits off the Schultze Granite (Peterson, N.P., 1962; Olmstead and Johnson, 1966; Balla, 1972), the San Manuel Deposit (Creasey 1965; Thomas, 1966), the Johnson Camp, I-10, Dragoon, and Strong and Harris Deposits off the Texas Canyon Pluton (Cooper and Silver, 1964), the Metcalf-King Deposits in the Morenci District (Lindgren, 1905; Moolick and Durek, 1966), the Safford (Lone Star) Deposit (Cook and Robinson, 1962), and the Tyrone Deposit in New Mexico. (Paige, 1922).
>
> Only the Sacaton Deposit north of Casa Grande is suggested to be off the southwest nose of the Three Peaks Monzonite (Balla, 1972). The location of twelve or so major mines off northeast noses and only one off a southwest nose of major northeast-trending plutons suggested an important question: What was the likelihood of a mineral deposit off the southwest nose of the northeast-elongate Schultze Granite under the volcanic cover between Pinal Ranch and Superior?

Drill hole A-8 was the discovery hole in that from 3,879 to 4,525 feet, the 646-foot section averaged 1.57% copper, with chalcopyrite-bornite mineralization.

This deep target has been drilled, Figure 10, for 3,000 feet northwest by 2,500 feet northeast. The mineralization has been cut by several northeast-trending faults which downdrop the zone to the northwest. Depth to sulfides average 4,010 feet below the surface on the south, 4,070 feet in the middle, and 4,480 feet to the northwest.

The deposit is open in plan, however, present interpretations suggest the drilled portion is part of a ring structure with a barren central core, similar to that suggested for the Ray deposit (Phillips, 1974).

O.K., let's return to the Oak Flat campground and have lunch while trading tales with the underground group.

Don't forget – LAST GUY, PLEASE CLOSE the GATE!

STOP 5

When you leave the campground, please spread out going back toward Superior.

Immediately after going through the Queen Creek Tunnel, turn left across traffic, when permissible, and pull into the wide parking area. Uphill traffic may be tight at times and will cause some problem going left—thus, we need space between vehicles so as to not stop in the right hand lane and cause more problems here!

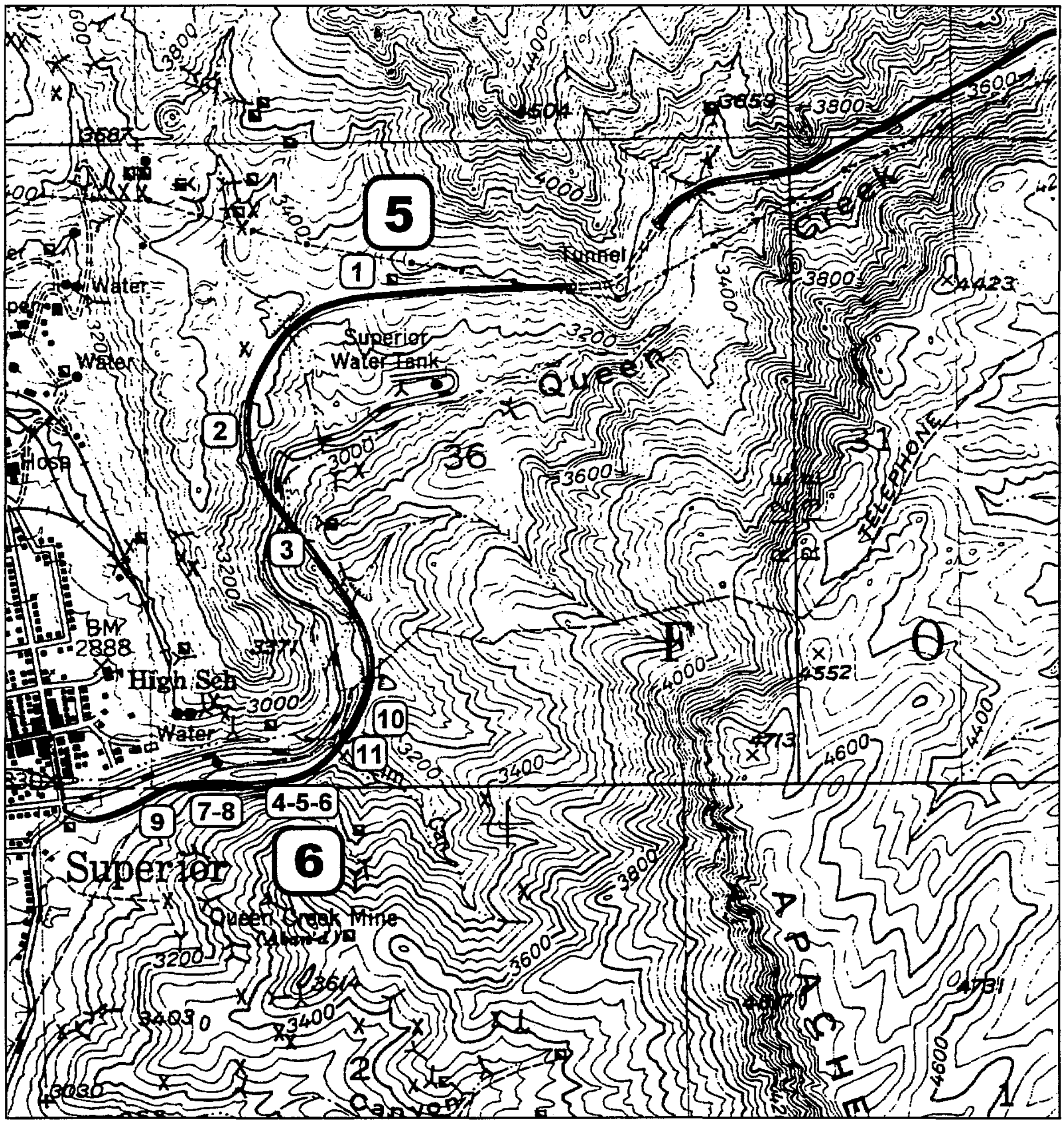


Figure 11. Stops 5 and 6 with the 11 geochemical sampling sites.

Unit	Sample	Footage	ppm						ppb
			Cu	Mo	Pb	Zn	Mn	Ag	Hg
Naco Limestone Middle Replacement	1	6	200	5	700	1500	53,000	50	105
Escabrosa Limestone Upper Replacement	2	10	200	30	2000	5000	130,000	100	220
	3	6	500	100	5000	5000	65,000	100	—
	A-4-1	10	3000	*	100	3000	3000	—	—
	A-4-2	10	5000	*	50	2000	3000	—	—
Escabrosa Limestone Middle Replacement	4	50	70	30	3000	1000	200,000	50	—
	5	1	500	20	1000	7000	2000	1	—
	6	50	20	*	100	200	1500	1	45
	A-4-3	10	500	15	*	2000	100	—	—
Martin Limestone Lower Replacement O'Carroll bed	7	5	300	10	1000	2000	1000	*	—
	8	12	50	*	50	200	2000	1	45
Bolsa Quartzite	9	50	50	*	*	*	300	*	135
LS&A Vein	10	20	20	2	50	200	10000	10	65
	11	100	200	15	2000	10,000	25,000	100	125

Unit	Sample	percent				Remarks
		Fe	Ca	Mg	SiO_2	
Naco Limestone Middle Replacement	1	2.0	3.0	0.03	76.0	mineralized replacement textures
Escabrosa Limestone Upper Replacement	2	2.0	7.0	0.02	37.7	mineralized replacement textures
	3	2.0	15.0	0.20	11.8	struc. w/lateral lms. repl. text.
	A-4-1	1.0	—	—	12.8	lms., bx., w/sec. CuOx
	A-4-2	1.0	—	—	20.5	lms., bx., w/sec. CuOx
Escabrosa Limestone Middle Replacement	4	3.0	5.0	0.02	24.5	struc. w/lateral lms. repl. text.
	5	33.3	5.0	0.10	4.0	total Fe repl. bed.
	6	1.0	23.2	5.00	1.8	repl. text. beds on both sides of sample 5
	A-4-3	37.3	—	—	36.9	total Fe repl. bed.
Martin Limestone Lower Replacement O'Carroll bed	7	33.0	1.5	0.20	37.9	total Fe repl. bed.
	8	1.0	26.0	5.00	1.7	repl text adj to sample 7
Bolsa Quartzite	9	5.0	0.10	0.05	90.0	weakly mineralized
LS&A Vein	10	1.0	24.0	0.10	—	in Naco, minor fract., above shale
	11	1.0	0.2	0.05	—	in Upper Escabrosa, mushroom, below shale

NOTE: mineralization is oxidized.
Dash (—) indicates no results for this sample.
Asterisk (*) signifies results reported were less than 2 ppm Mo; 25 ppm Pb; 200 ppm Zn; or 1 ppm Ag

Table 1. Geochemical data of samples from sites 1 through 11.

The site 1 in Stop 5 area is 2,500 feet vertically above the Devonian A-bed mineralization, west of the NS5W fault (the fifth north-south fault named). We are in the Pennsylvanian Naco Limestone section. It has numerous bleached beds in both the limestone and shale units. Numerous calcite veins subparallel to the east-west Magma Vein, located 1,000 feet north of the road, are in the units. On the south bank are several weak skarn-looking units. Iron and manganese have been added to some of the units.

Table 1 contains geochemical data for the sites 1 through 11.

At the east end of the parking area is a view point. Looking south over the water tank is the thin-bedded Naco, and at its upper contact, semi-saddle, is a yellowish zone of Whitetail Conglomerate, about 80 feet thick. This is the thickest section peeking out along the western front of the dacite. Dacite cliffs and the "Apache Leap" portion is along the south above the Whitetail.

Looking back to the west, past the new Queen Creek bridge, the workings left by the manganese miners are evident. Far out the gap of Queen Creek is the younger basin-filling volcanics.

The sample 1, taken in the north wall of the cut, is 3,500 feet up-dip from the "blind" Naco ore zone which has been mined. The zinc-manganese-silica values are indicative of the mineral fringes (especially up-dip) of the massive replacement deposits at Superior. Note also the anomalous silver value.

For those walking on down to the upper replacement zones of the Escabrosa Limestone, just below the Maroon Shale marker bed, the Samples 2 and 3 were collected four to five thousand feet up-dip (westward) from the "blind" Escabrosa C-C" bed. Note the lead-zinc-manganese-silver values and the moly in Sample 3. The A-4 drill hole samples reflect the silica addition and lower, but appreciable, lead-zinc-manganese. The higher copper values in the A-4 samples are the result of secondary copper oxides.

The vehicles should now move on down the hill. Take the off-ramp into Superior and turn hard right onto the parking of the old Highway 60.

STOP 6

Refer to Figure 11 for the sites to be discussed, and Table 1 for the geochemical data.

We will walk south, up AZ 177 on the bridge over US 60 East. The rock in the cut is Gila Conglomerate. Walk on down the on-ramp to Globe, and at the end of the east-bound on-ramp, two water pipes can be seen on the south bank.

The steep west-dipping, Concentrator Fault strikes north-south here and separates Quaternary Gila Conglomerate from Precambrian diabase.

Be careful walking east alongside the highway, and from diabase you'll pass by the red-stained Cambrian Bolsa Quartzite (Sample 9). The iron-stained and altered quartzite has an anomalous value of mercury and the high iron.

On ahead, just past the quartzite contact, is the lower Devonian ore bed (A-bed, O'Carroll bed) with samples 7 and 8. The O'Carroll stratigraphic horizon is one of the most persistent replacement horizons in Central Arizona, and generally reflects any nearby mineralization source for a longer distance than any other stratigraphic unit. The samples 7 and 8 show strong lead-zinc-manganese-silica additions over other Martin Limestone horizons (not listed here).

Moving up traffic, the main C-bed Escabrosa unit has three samples (4, 5, and 6). The entire range of values are elevated, including the sample from A-4. The dusky, replacement texture of this outcrop is typical of the better developed zones outside of ore.

The upper Escabrosa replacement horizon is not found in this section of outcrop, but was seen by those who walked down the road from STOP 5, and looked at points 2 and 3.

The section of outcrop along which we have just walked is between two east-west trending faults—the LS&A on the north along the creek and up ahead, and the Queen Creek Mine Fault to the south. When they built the new road, they broke into the Queen Creek Mine workings and did some back filling to stabilize the road. Thus, we cannot say that these values are indicative of the C-bed which is plus 5,000 feet east of here, however, they are indicative of the type found associated with mineralization.

Continue up along the curve to the manganiferous zone of the LS&A Fault. Climbing the hill, you'll see the Maroon Shale marker bed. Sample 11 was collected from the mushroomed manganese below the shale, while sample 10 was taken above the shale in the Naco Limestone. It is obvious that the shale acted as a trap for the mineralization at this point. When you return to your library, you may be interested in reading Hausen (178), p.4 and 5, where he discusses the early work by Newmont on the Superior stratiform replacement (manto) deposits.

While you are up on the slope, you might look for the small outcrops of porphyry among the Naco bedding (Peterson, D.W., 1962).

As the sun is setting behind Picketpost Mountain, Thank You for the Outing at Superior, and Thanks to Magma Copper Company!

Have a
safe journey
home.

Notes

🕮 Things To Read!

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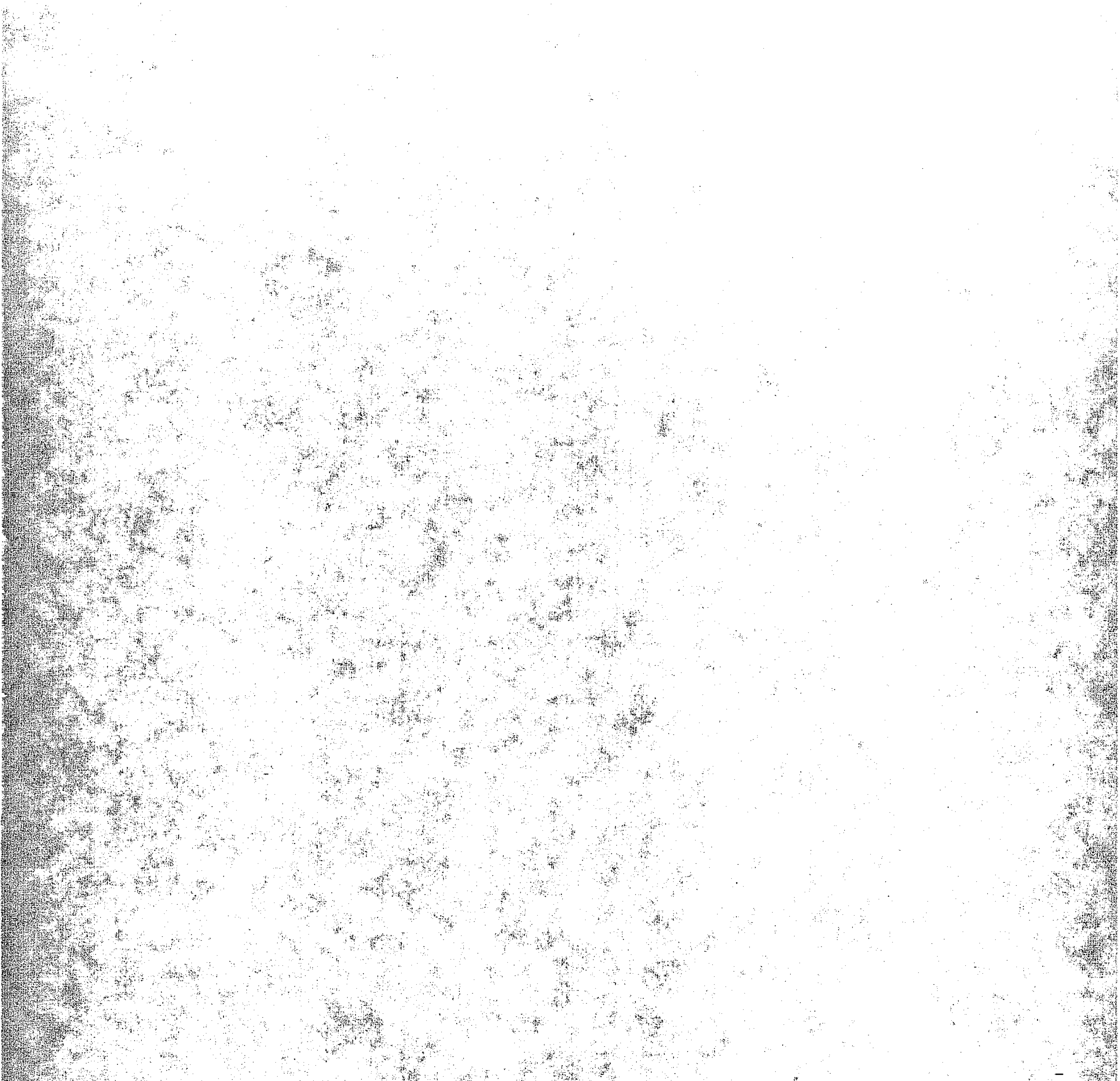

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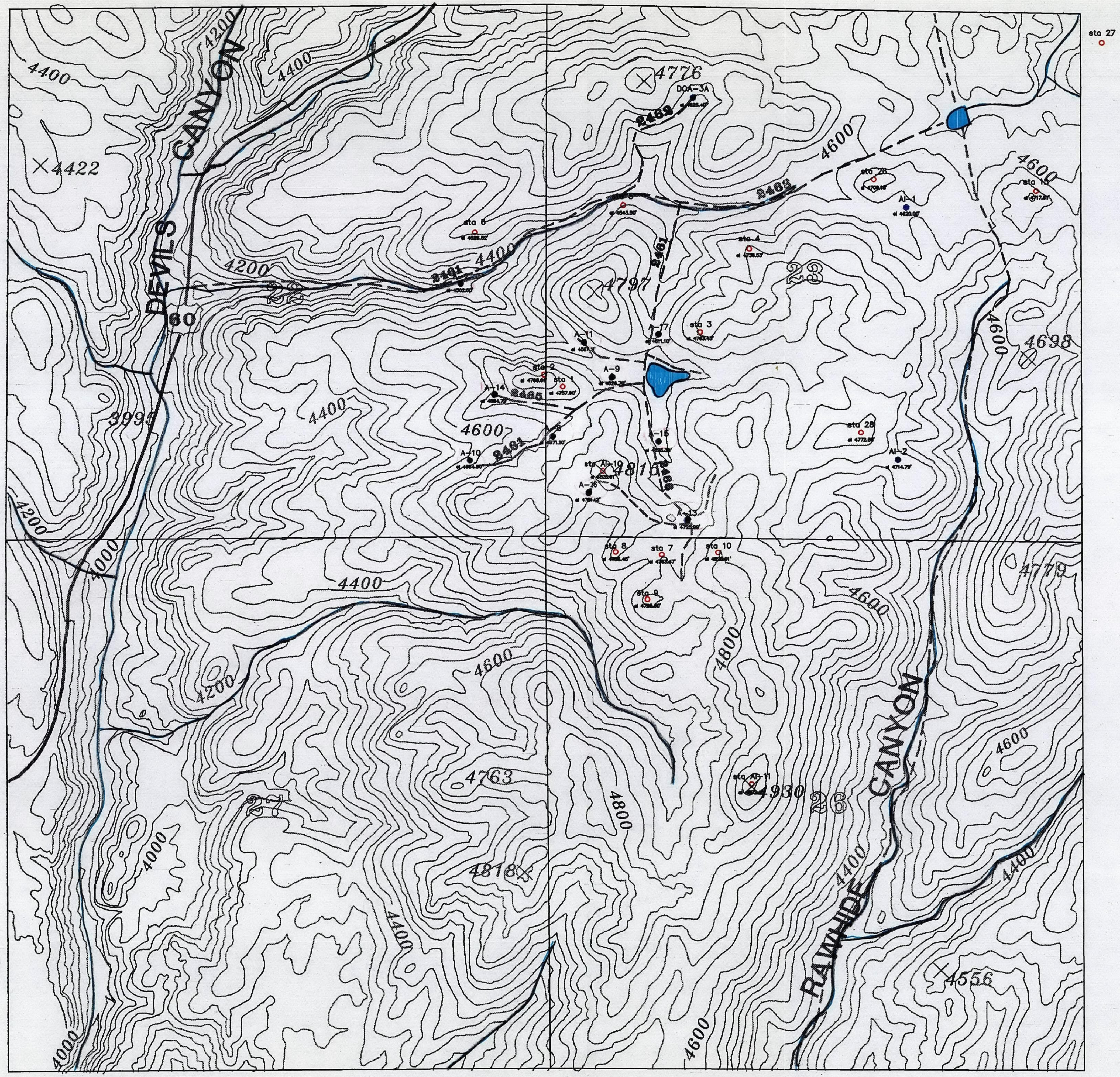


ASARCO SOUTHWESTERN EXPLORATION

SUPERIOR EAST PROJECT
DRILL HOLE - STATION MAP

PINAL COUNTY, ARIZONA

0 1000 2000

FEET

mn SE921018 10/28/92

I'm not sure that last try worked.

To: James D. Sell
fax (520) 578-7196

September 19, 1995

Jim,

Yeah, I'd be thrilled if you'd include those abstracts in your field guide, especially if you include your paper on Superior East in the same volume. If AZ Digest Volume 20 is the proceedings volume from the symposium last year, I still haven't received it yet. Some printing error I hear. Your Superior East paper will certainly be referenced all of my future writings, even if I have to cite it as "in press."

You are correct about why I didn't explicitly reference the ASARCO Superior East porphyry (a combination of space limitations in the abstract and closed-mouth-itis). I agree with your wanting to connect Superior with Superior East, even though *some might* argue that the distance between them is a bit far (a little further than I like my standard *"Disseminated"* porphyry coppers to reach, but quite reasonable for *"Cordilleran Lode-type"* porphyry coppers [terminology of Einaudi 1982 in Titley Advances in the Geology of Porphyry Coppers volume]). I made map of the Butte district (lifted it directly out of the Graton-Sales volume) and scaled it to the same scale as my district-scale maps of the Superior/Superior East district (to act as an overlay). The similarity is striking! By *coincidence*, the vein orientations are the same in both districts, and there appears to be a major normal fault in both districts at the same location (Continental Fault of Butte = inferred Devil's Canyon Fault of Superior/Superior East). The Superior district corresponds spatial to the zone of Butte-type veins (Anaconda and Blue systems) at Butte and the Superior East porphyry corresponds precisely with the Continental pit disseminated porphyry copper deposit of Butte. The distances involved are certainly not an issue! Your observations that the Superior East porphyry is dominated by dikes and sheeted chalcopyrite-poor veins (i.e. high sulfidation state copper mineral assemblages) supports the Cordilleran Lode-type porphyry model (dominated by a strong structural control on magma emplacement and vein formation). My work has brought to light some other evidence supporting the link, but I still need to get permission to disseminate that publicly. I definitely think you are right on in linking Superior and Superior East.

I may be able to put together one more little piece to put in the fieldguide before October 1, but don't wait up for me. I need to pass it by Magma first.

Kurt

Kurt Friehauf
fax (415) 725-0979

20

Skarn and Cu-(Au)-rich massive sulfide/specularite carbonate-replacement deposits of the Superior District, AZ

Kurt C. Friehauf, Dept. of Geological and Environmental Sciences, Stanford University, Stanford CA 94305-2115

The presence of pre-mineral porphyry dikes, skarn followed by high-sulfidation, enargite-bearing Cu-Au veins and pebble breccias suggest the manto ores of the Superior district are similar to the carbonate-hosted ores of Tintic (UT), Bisbee (AZ), Yauricocha (Peru), Morococha (Peru), and Cananea (Sonora) and the carbonate-hosted analogues of high-sulfidation base metal lode veins such as at Butte (MT), Bor (Yugoslavia), Recsk (Hungary), Srednegorje (Bulgaria), Chuquicamata (Chile), Lepanto (Philippines), and Nena (Papua New Guinea).

East-dipping Paleozoic carbonates in the Superior District (26 Mt 4.7% Cu, 1 ppm Au, 45 ppm Ag, Matt Knight, Pers. Comm., 1994)) host garnet, amphibole, and talc skarn and stratabound massive specularite-copper sulfide and Pb-Zn sulfide replacement ("manto") ores where E-W-striking, enargite-bearing veins (e.g. Magma vein) intersect favorable carbonate lithologies. Favorable strata occur near the base of the Devonian Martin Formation (5 m thick "A-bed" dolostone), the lower part of the Mississippian Escabrosa Limestone (< 60 m thick dolomitic and calcitic "C-bed"), and below and above the shale at the base of the Pennsylvanian Naco Limestone (5 m thick "D-" and E-bed"). Hydrothermal fluids did not react visibly with "non-favorable" carbonate strata.

Garnet-amphibole-pyrite-(sphalerite) skarn, followed by rhythmically-layered sphalerite-magnetite-talc bodies, pre-date specularite-copper sulfide manto formation. Garnet-bearing skarn occurs predominantly as east-striking veins (i.e. the same fracture set occupied by copper ores and pre-mineral porphyry dikes) with small mantos flaring out in favorable members of the "D-bed". Amphibole-bearing skarn consists of an early, forest green, fine-grained (2-3 mm grains) variety growing on and cutting compositionally-zoned garnet grains which is in turn cut by light green coarse-grained (10-15 mm) amphibole veins. No copper minerals precipitated during skarn formation. Garnet is weakly altered to soft, tan-colored clay and locally specularite where cut by pyrite-bornite ± specularite-calcite veinlets. Skarn amphiboles have been altered to talc. Rhythmically-banded talc-magnetite skarn replaces dolomitic units and locally contains talc-altered coarse-grained amphibole veins.

Massive galena-pyrite-sphalerite-quartz mantos (< 1m thick) and replacement veins lacking associated talc alteration occur as separate bodies from the main specularite-copper-sulfide mantos. No magnetite or specularite and only traces of chalcopyrite precipitated with galena-bearing massive sulfide. Sphalerite displays chalcopyrite disease and pyrite is locally platy (a la Leadville, CO).

Massive specularite-sulfide mantos (5-60 m thick, < 90 m wide, and < 300 m down the dip) post-date skarn and consist of coarse-grained specular hematite, pyrite, chalcopyrite, bornite, minor chalcocite, and < 5% quartz. Rock types tend to be either specularite- or sulfide-dominant (>80:<20) with sharp (< 25 cm) chalcopyrite-rich contacts between types. Sulfide-dominant (2-4 mm granular pyrite-chalcopyrite (85:15) ± bornite) bodies occur as coalescing elongate pods (typically 6-25 m) within a "sea" of specularite-dominant (80-95% 1-5 mm specularite + 5-10% 2-5 mm pyrite + <10% chalcopyrite) rock that generally extends to the sharp (<10 cm wide) contact with wall-rock carbonate. Specularite-dominant rock predominates in shallower levels, along the footwall, and along the northern margin of the manto, but sulfide pods predominate at intermediate levels. WNW-elongate sulfide pods (i.e. similar orientation to veins in the district) widen at some stratigraphic levels within the specularite-dominant zone of the C-bed orebody, possibly reflecting stratigraphic control on a late sulfidizing fluid flow into favorable replacement horizons within earlier specularite. NW and NNE-striking, irregular bornite-chalcopyrite and bornite-pyrite replacement veins and bornite-matrix pyrite-bornite- + pyrite-chalcopyrite-fragment breccias are the locus of high-grade Cu-Au ore within the sulfide pods. Bornite veins commonly have rhythmically-banded bornite-pyrite or nebulous bornite-chalcopyrite/chalcopyrite-pyrite selvages. Paragenetic relations suggest an early stage of specularite + minor pyrite-chalcopyrite replacement of carbonate followed by formation of sulfide-dominant zones by sulfidation of specularite to replacement veins and masses of pyrite, chalcopyrite and bornite. Even, nearly continuous 0.1 - 0.5 cm specular hematite rinds on small (<30 cm thick) massive pyrite >> chalcopyrite mantos in limestone, suggest specularite also precipitated as a peripheral mineral zone during introduction of Cu-Fe sulfides.

Wall-rock alteration peripheral to specularite-copper sulfide mantos is characterized by mm-scale white dolomite or calcite veinlets ± specularite veinlets with bleached halos, and white talc spots (2-40 mm diam.) in dolomite within meters of the contact. Small (< 1 m) pyrite-chalcopyrite mantos do not visibly alter limestone. A 20-foot thick, quartz-eye-poor, hornblende-rich "latite" porphyry dike, where cut by massive sulfide/specularite mantos, is pervasively altered to sericite-pyrite and chlorite and cut by quartz-sericite-pyrite, specularite, and quartz-adularia ± chlorite veins. Hornblende sites were locally replaced by specularite.

21

Carbonate-replacement Cu-(Au) deposits associated with a high-sulfidation state Butte-type vein system, Superior District, AZ

Kurt C. Friehauf, Dept. of Geological and Environmental Sciences, Stanford University, Stanford CA 94305-2115

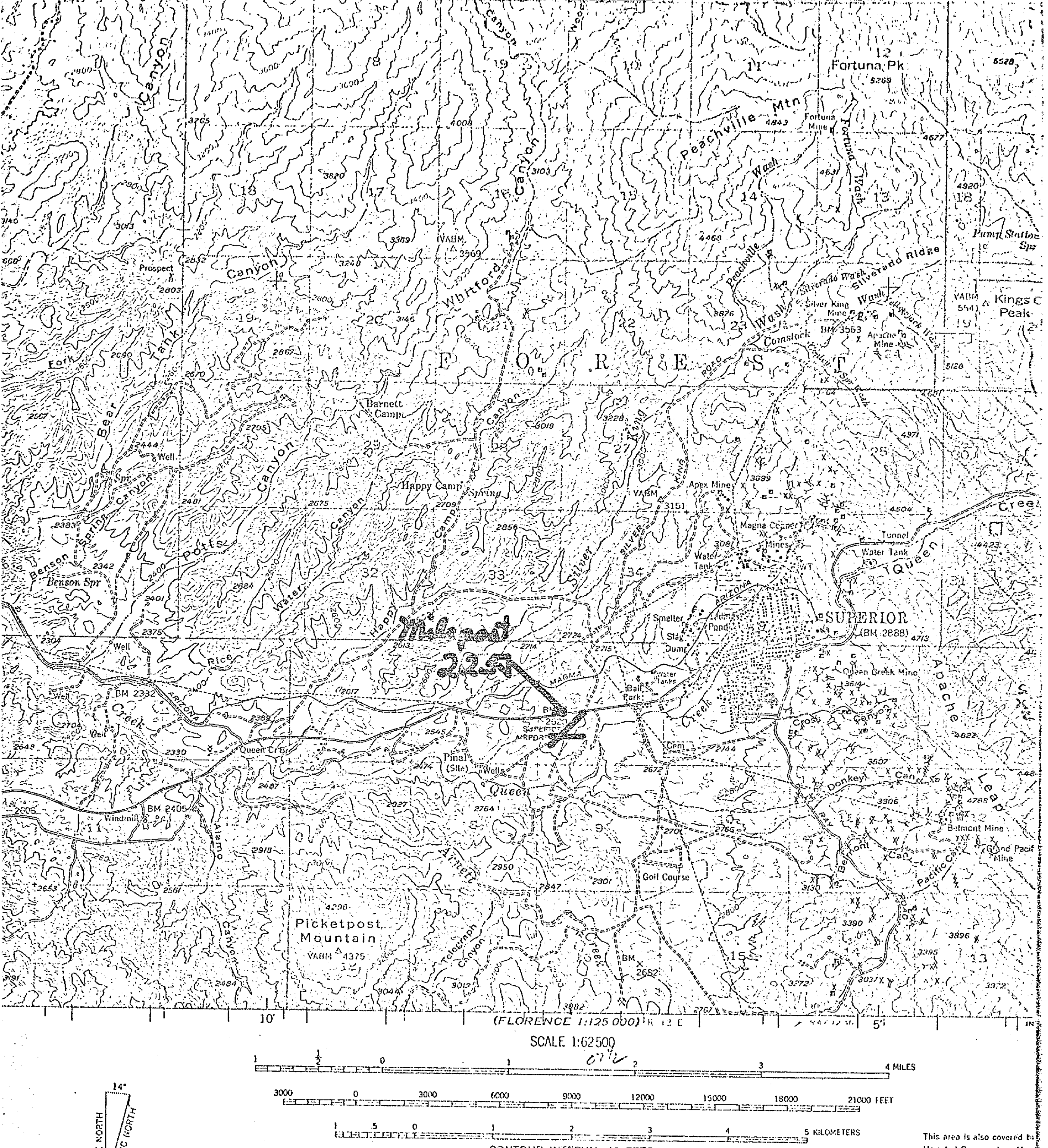
Copper veins in the Superior district closely resemble quartz monzonite-hosted "Main stage veins" at Butte (MT), Tintic (UT), Yauricocha (Peru), and Chuquicamata (Chile) in vein filling mineralogy and associated alteration. Carbonate-hosted ores in the Superior district are similar to the carbonate-hosted ores of Bisbee (AZ) and Yauricocha (Peru). The association of Butte, Yauricocha, Chuquicamata, and Bisbee with porphyry copper systems suggests Superior is related to an as-yet undiscovered porphyry copper system.

East-dipping Paleozoic carbonates host the stratabound massive specularite-copper sulfide and Pb-Zn sulfide replacement ("manto") ores where E-W-striking, enargite-bearing veins (e.g. Magma vein) intersect favorable carbonate strata. Favorable strata occur near the base of the Devonian Martin Formation (5 m thick "A-bed" dolostone), the lower part of the Mississippian Escabrosa Limestone (< 60 m thick dolomitic and calcitic "C-bed"), and below and above the shale at the base of the Pennsylvanian Naco Limestone (5 m thick "D-" and E-bed"). "Nonfavorable" limestone and dolostone beds that lie between the favorable horizons show little visible evidence of fluid-rock interaction more than a meter from the feeder veins.

Footwall contacts of mantos are locally discordant (on the order of a meter), but hanging wall contacts are discordant by up to tens of meters. Portions of mantos tend to be either specularite- or sulfide-dominant with sharp (< 25 cm) contacts between zones. Early replacement of carbonates by massive specular hematite with 5-15% disseminated pyrite and chalcopyrite was followed by the formation of massive pyrite-chalcopyrite ± bornite replacement veins and mantos *within* the specularite body. The time-integrated mineral association zoning is from central bornite+chalcopyrite+pyrite+quartz outward to pyrite-chalcopyrite-quartz to specularite+pyrite+chalcopyrite. Small, isolated massive galena-sphalerite-pyrite-quartz pods within limestones/dolostones occur peripheral to copper orebodies.

Wall-rock alteration adjacent to specularite-copper sulfide mantos is characterized by mm-scale white dolomite or calcite veinlets ± quartz-specularite veinlets with bleached halos within meters of the contact. At one locality, a latite porphyry dike in contact with a manto is pervasively altered to sericite-pyrite and chlorite and is cut by quartz-sericite-pyrite, specularite, and quartz-adularia ± chlorite veins. XRD analyses of siliceous sulfide breccias in the central zone of the C-bed orebody indicate the presence of dickite and zunyite -- minerals typical of hypogene advanced argillic alteration in quartzofeldspathic rocks in other Butte-type systems -- suggesting manto ores at Superior represent the carbonate-hosted analogues of advanced argillic alteration.

SEG Carbonate Conference -- St. Louis MO 1995



CONTOUR INTERVAL 40 FEET
DATUM IS MEAN SEA LEVEL

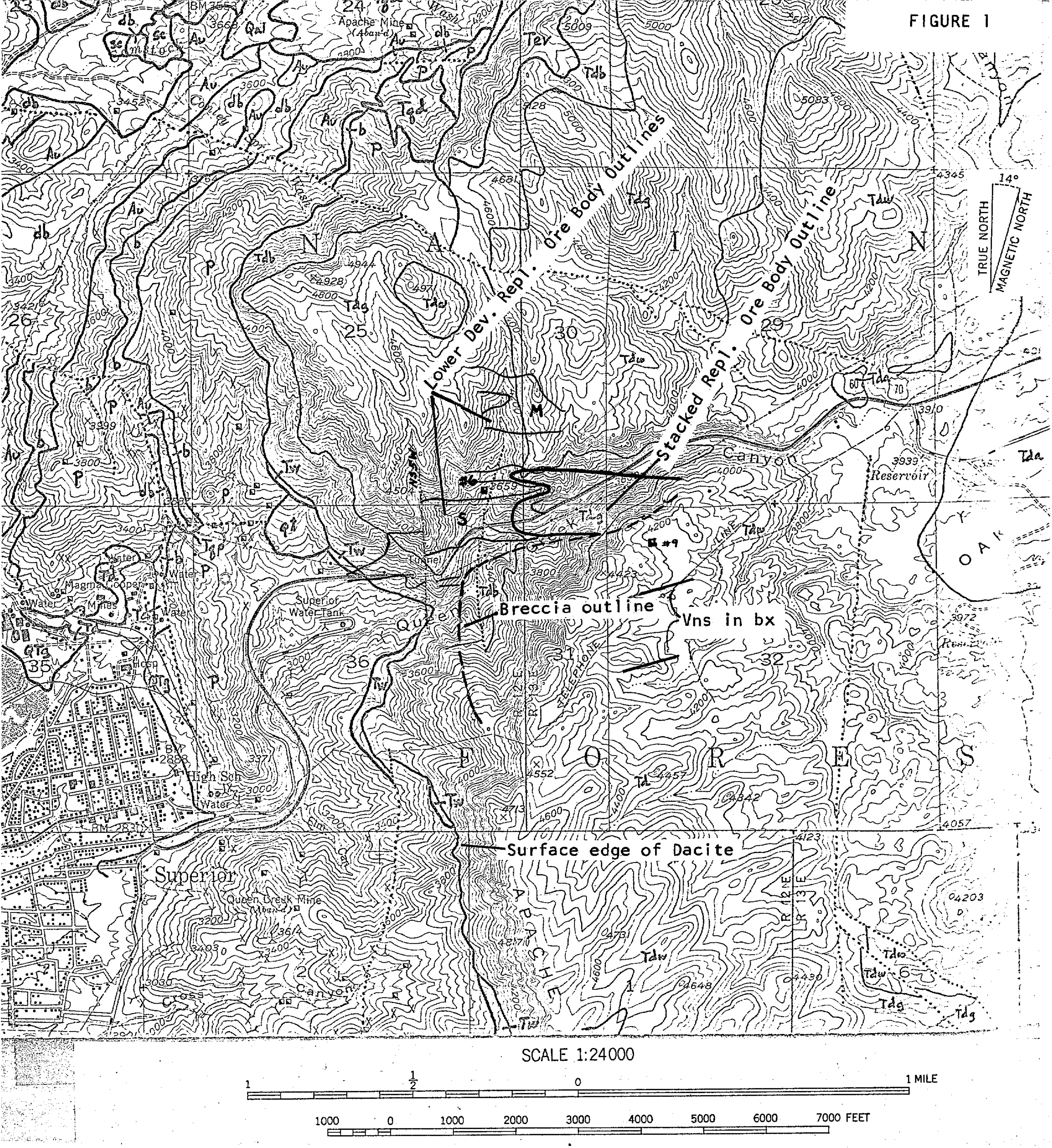
This area is also covered by
Haunted Canyon, Iron Mou
Superior 7½ minute quad

APPROXIMATE MEAN
DECLINATION, 1948

STOP ONE. Superior Airport Overlook

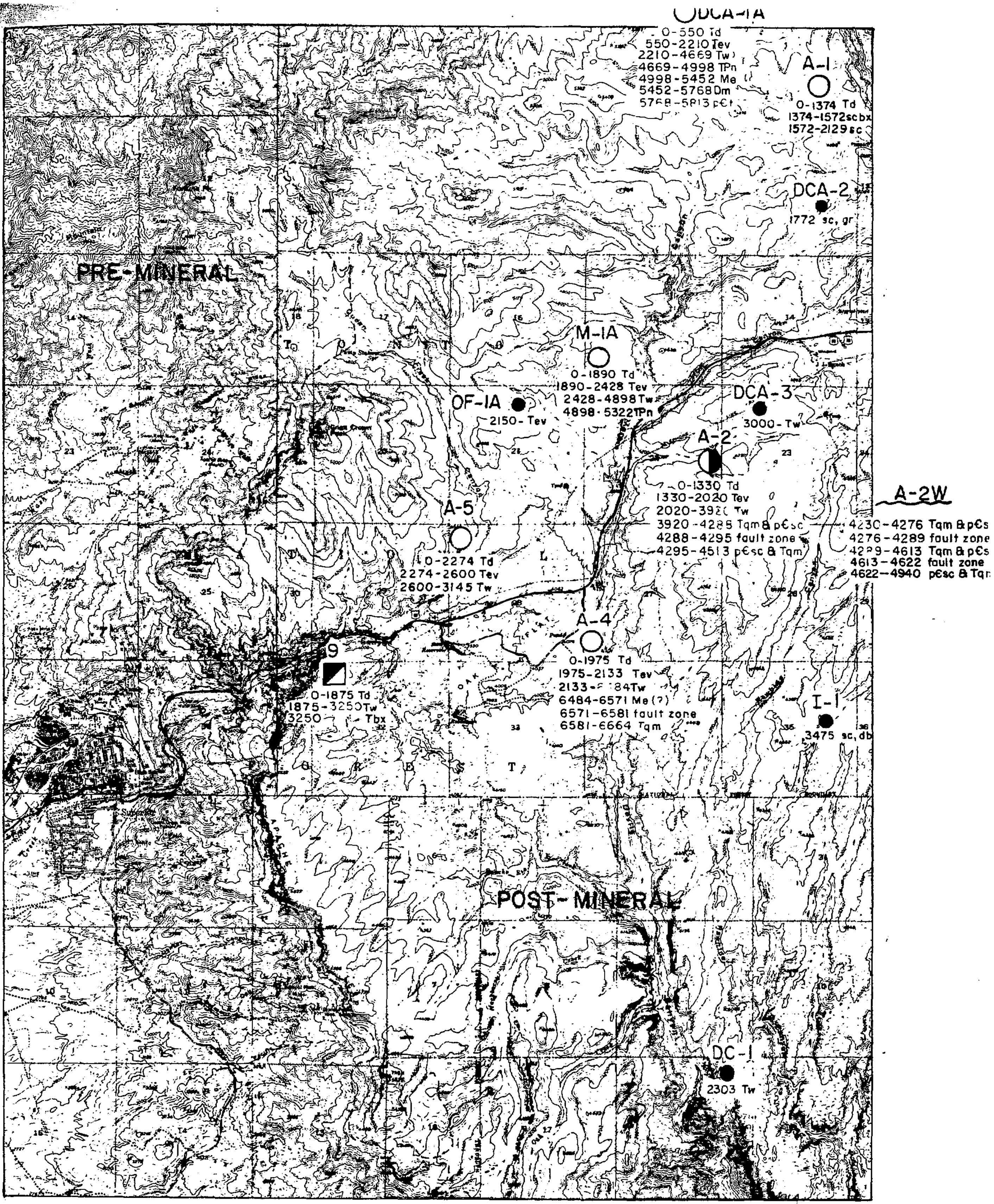
THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U. S. GEOLOGICAL SURVEY, FEDERAL CENTER, DENVER, COLORADO OR WASHINGTON 25, D. C.
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST

FIGURE 1



CONTOUR INTERVAL 40 FEET

DATUM IS MEAN SEA LEVEL



EXPLANATION

- ● Previous drill hole
- ● ASARCO drill hole
- ◪ Magma's #9 shaft

DCA-1 (hole designation)
○
4011 Tw
↳ Rock type
→ Bottom hole depth
P

POST-MINERAL ROCK UNIT

Td - Dacite
Tev - Early volcanics
Tw - Whitetail

PRE-MINERAL ROCK UNIT

Tbx - Breccia	Dm - Martin lms
Tqm - Quartz Monzonite	p€t - Troy qtz
Tgr - Granite	p€db - Diabase
TPn - Naco limestone	p€sc - Schist

DRILLING PROGRESS MAP
for the month of MAY, 1972
SUPERIOR EAST

GILA & PINAL COUNTY, ARIZONA
SCALE: 1" = 1 mile J.D.S.
2463

AMERICAN SMELTING AND REFINING COMPANY
TUCSON ARIZONA

September 21, 1973

CONFIDENTIAL

FILE MEMORANDUM

Occidental
Miami East

The following information was obtained from Occidental Minerals:

Size -- +100 million tons 200 million (mostly within the 100-million ton area)

Grade -- 0.55% Cu 0.4% Cu

Rock -- 10% porphyry; 90% schist

Mineralogy -- 75-80% oxide (2/3 malachite, azurite
1/3 chrysocolla - mainly in porphyry)
20-25% chalcocite, little native copper, cuprite, etc.

Leaching -- Test on core recovered 72% of total copper.

Geometry -- Tilted blanket 100-600' thick, average about 300'; 1200 to 1600' beneath surface -- tilts SE.

Suggested Mining -- excavate 15 to 20% to allow caving (just to top of ore) then leaching in place.

Property -- 1) Van Dyke mineral ground --
5% NSR until total price $3 million paid.
2) 20 acres city lots -- $20,000 x 80 ≈ $1,600,000
3) Surface options 40-50 @ $30,000 ≈ $1,500,000

Purchased 1 sq. mile near Copper Hills for $300 A; that could be subdivided.

AMAX is turning property back to Occidental on November 29, 1973.

W. L. Kurtz

WLK:lb

AMERICAN SMELTING AND REFINING COMPANY
TUCSON ARIZONA

November 28, 1973

TO: W. L. Kurtz

FROM: J. D. Sell

Comparative Results
Emission Spectrographic Analysis
Superior East & Bohme Project Areas
Pinal and Gila Counties, Arizona

Some fifty-one samples, collected from surface outcrop and drill hole cuttings or core, have been compiled as an interpretive guide to drill hole intercepts and known ore bodies.

Two attachments are utilized:

A) Map showing sample points and ore body distribution.
B) Chart listing analysis results, for various elements, by equivalent rock types or units.

Quartz Monzonite and Schultze Granite. The three granite samples are consistent for the samples listed and may be considered normal for the district. The slightly altered sample (SC-2) shows a slight gain in copper only. In contrast, the three drill hole samples of A-2 and A-4, in altered quartz monzonite, show twenty-five to several hundred-fold increase in copper values and ten to twenty-fold increase in moly values. A somewhat decrease in manganese values is shown in the quartz monzonite samples under that found in the fresh granite samples. (Note: the sample PR-1 was taken next to the main highway near Sutton Summit. Could the recorded value of 30 ppm lead be indicative of automobile exhaust contamination, as all other samples of this group contained 15 ppm or less?)

Naco Limestone-Middle Replacement. The sample QC-1 was taken some 3500 feet up-dip from the "blind" Naco ore body now being developed to the east of the sample point by Magma Copper. The zinc-manganese values and the addition of silica are indicative of the mineral fringes (especially up-dip) of the massive limestone replacement deposit at Superior. Note also the anomalous silver value. The other two samples from drill hole DCA-1A were from shaley limestone units without any appreciable replacement texture.

Naco Limestone-Lower Replacement. The one sample, taken also from drill hole DCA-1A, shows about the same background values as found in the middle replacement unit.

Escabrosa Limestone-Upper Replacement. The two QC-series samples were collected four to five thousand feet up-dip (westward) from the "blind" Escabrosa ore body at Magma. Note the lead-zinc-manganese values and the silica addition. The values are many magnitudes higher than the DCA-1A samples or published background values for limestone. The A-4 drill hole samples reflect the silica addition and lower, but appreciable, lead-zinc-manganese values. The higher copper values in the A-4 samples are the result of secondary copper oxide and cannot be equated. The JH-sample from Jewell Hill is less than thirty-five hundred feet from the old Castle Dome limits and reflects significant geochemical values. Also note the QC-series and the JH-sample have a silver value above normal.

Escabrosa Limestone-Middle Replacement. The QC-series were taken along a strong, but presently undeveloped, vein system and the results reflect the lead-zinc-manganese and silica addition. Anomalous moly is also associated with the samples. The Jewell Hill (JH) sample has strong values. Drill hole A-4 also reflects strong copper-zinc and silica values. Likewise, the AH-1 hole is strongly indicative of being in the similar zone of mineral influence and near a major mineral source. The samples from AH-2 and DCA-1A are very weak. Note also that the QC-, JH-, and AH-1 series of samples contain anomalous silver and cadmium-tin. The A-4 sample was not run by emission spectrography and I can only project that it would have contained some anomalous values of the type shown above.

Escabrosa Limestone-Lower Replacement. Only two samples of this horizon were collected and, as shown, the AH-1 sample is decidedly anomalous (including silver) and is comparable to other horizons in the Escabrosa. The AH-2 sample is again of low magnitude and reflects a distance from a mineralized source.

Martin Limestone-Middle Replacement. This series of results all were taken in replaced textured limestones and contain added silica, but very mixed values in other elements. No real anomalous values, when compared to other limestone values, except for the moly in DCA-1A. This moly value was secured by regular AA determination and may be somewhat high in relation to ES determinations.

Martin Limestone-Lower Replacement (O'Carroll Bed). The O'Carroll stratigraphic horizon is one of the most persistent replacement horizons in Central Arizona, and generally reflects any nearby mineralization source for a longer distance from the source than any other replacement horizon unit. All samples collected (except DCA-1A which contains incomplete data) show strong lead-zinc-manganese and silica addition when compared to other Martin Limestone horizons. Again, the DCA-1A moly sample may be in error on the high side, but the increased silica suggests the sample is affected. The anomalous QC-, AH-1, and JH-1 samples also have silver, bismuth, and tin values.

Bolsa Quartzite. No comparison.

Dripping Spring Quartzite. No comparison.

Manitou Granite. All samples are comparable and suggest only that the separated blocks sampled all came from a common mass.

Pinal Schist. Poor control precludes definitive comparison, but the A-2 samples indicated strong addition of copper-moly values and some silica in comparison to the sulfide sample of SC-1. The SC-1 sample was taken from churn drill cuttings in the SR-series samples. The oxidized native and the large amount of transported copper oxide in the SR-series is also reflected. The SR-13 series show lead values above any of the other samples.

James D. Sell
James D. Sell

JDS:lb
Attachs.

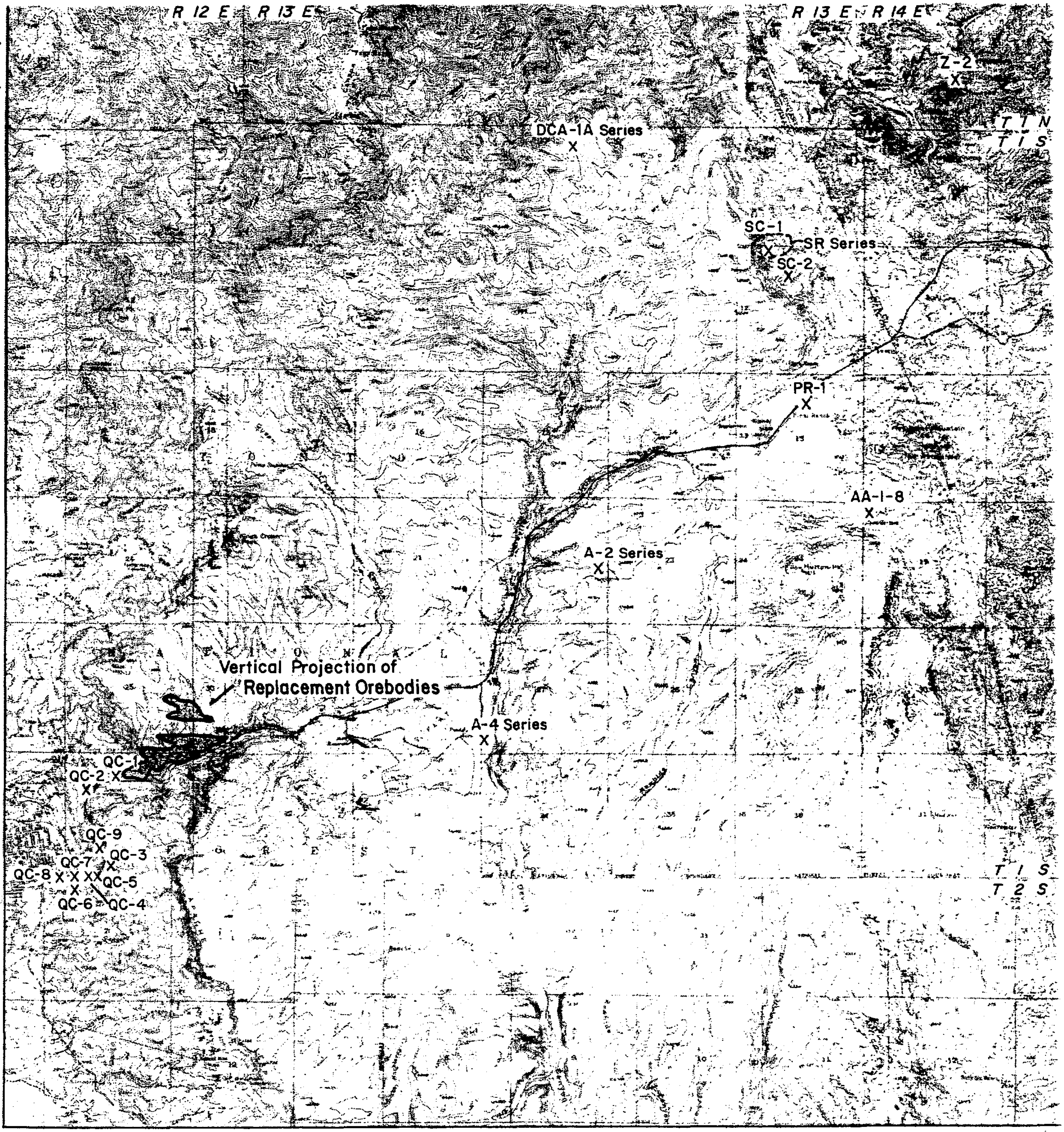
X Sample Points For Emission Spectragraphic Analysis

BOHME PROJECT AREA

GILA COUNTY, ARIZONA

Scale 1:24,000

JDS Nov. 1973



X Sample Points For Emission Spectrographic Analysis

SUPERIOR PROJECT AREA

GILA & PINAL COUNTY, ARIZONA

Scale : 1" = 1 mile

JDS Nov 1973

ATTACHMENT B

SEMI-QUANTITATIVE EMISSION SPECTROGRAPHIC ANALYSIS RESULTS

			ppm					%				ppm				
	Sample #	Footage	Cu	Mo	Pb	Zn	Mn	Fe	Ca	Mg	SiO_2	Ag	Bi	Cd	Sn	Remarks
Qtz. Monzonite	A-2C-3	10	700	5	*	*	100	1.5	0.07	0.10	77.2	*	*	*	*	Strong silicification, mixed.
	A-2C-17	10	3,000	20	*	*	150	5.0	0.01	0.20	73.6	*	*	*	*	Moderate argillic alt., mixed.
	A-4C-124	10	500	40	-	-	-	-	-	-	-	-	-	-	-	Weak argillic (sulfides).
Schultze Granite	SC-2	10	100	2	*	*	200	1.5	0.50	0.20	74.7	*	*	*	*	Slight alt. w/FeOx on fractures.
	AA-1-8	15	10	*	*	*	300	1.5	1.00	0.20	70.2	*	*	*	*	Fresh.
	PR-1	20	7	*	30	*	500	2.0	1.00	0.20	72.2	*	*	*	*	Fresh.
Naco Lms. Middle Repl.	QC-1	6	200	5	700	1,500	53,000	2.0	3.00	0.03	76.0	50	*	*	*	Mineralized repl. text.
	DCA-1A-8	20	6	7	-	*	-	-	-	-	-	-	-	-	-	Shaley Lms., no repl. text.
	DCA-1A-9	20	7	5	-	*	-	-	-	-	-	-	-	-	-	Shaley Lms., no repl. text.
Naco Lms. Lower Repl.	DCA-1A-10	20	5	7	-	*	-	-	-	-	-	-	-	-	-	Shaley Lms., no repl. text.
Escabrosa Lms. Upper Repl.	QC-2	10	200	30	2,000	5,000	130,000	2.0	7.00	0.02	37.7	100	*	*	*	Mineralized repl. text.
	QC-9	6	500	100	5,000	5,000	65,000	2.0	15.00	0.20	11.8	100	*	*	*	Vn. struc. w/lateral lms. repl. text.
	A-4C-95 A4-1	10	3,000	*	100	3,000	3,000	1.0	-	-	12.8	-	-	-	-	Dolo. lms., bx, w/sec. Cu oxide.
	A-4C-96 -2	10	5,000	*	50	2,000	3,000	1.0	-	-	20.5	-	-	-	-	Dolo. lms., bx, w/sec. Cu oxide.
	JH-3	15	50	10	1,000	500	5,000	0.5	25.20	5.00	9.0	1.0	*	*	*	Repl. text., minor mineral.
	DCA-1A-12	8	19	13	-	*	-	0.8	30.70	20.80	3.7	-	-	-	-	Repl. texture.
Escabrosa Lms. Middle Repl.	QC-3	50	70	30	3,000	3,000	200,000	3.0	5.00	0.02	24.5	50	*	*	*	Vein structure w/lateral lms. repl. text.
	QC-4	1	300	20	1,000	7,000	2,000	33.3	5.00	0.10	4.0	1	*	*	10	Total Fe replaced bed.
	QC-5	50	20	*	100	200	1,500	1.0	23.20	5.00	1.8	1	*	*	*	Repl. textured beds on both sides of QC-4.
	A-4C-111 A4-3	10	500	15	*	2,000	100	37.3	-	-	36.9	-	-	-	-	Total Fe replacement.
	JH-2	10	100	3	7,000	2,000	7,000	2.0	24.50	5.00	15.3	2	*	50	*	Weak repl. text. & mineral.
	AH-1-20 & 21	8	52	*	5,400	1,100	9,400	1.3	24.00	0.60	24.8	8	*	*	*	Mineralized repl. text.
	AH-2-17, 18, & 19	12	4	*	*	*	160	0.7	20.50	8.70	7.3	*	*	*	*	Weakly mineralized.
	DCA-1A-15	9	33	9	-	*	-	0.8	31.8	20.00	2.5	-	-	-	-	Repl. text.
Escabrosa Lms. Lower Repl.	AH-1-28 thru 31	44	21	*	1,050	520	3,200	0.5	25.10	5.50	5.1	3	*	*	*	Bleached & mineralized repl. text.
	AH-2-23	34	7	*	*	*	100	0.7	22.40	15.00	4.6	*	*	*	*	Weak repl. text.
Martin Lms. Middle Repl.	AH-1-37	17	7	*	200	*	1,000	1.0	10.00	3.00	32.3	*	*	*	*	Weak repl. text.
	AH-2-27	17	3	*	*	*	500	2.0	23.20	10.00	11.3	*	*	*	*	Weak repl. text.
	DCA-1A-18	10	39	12	-	*	-	1.3	20.20	9.90	36.1	-	-	-	-	Repl. text.
Martin Lms. Lower Repl. O'Carroll	AH-1-42	8	150	15	1,500	10,000	3,000	10.0	1.00	1.00	44.2	10	20	*	10	Mineralized repl. text.
	JH-1	5	500	10	1,000	1,500	1,500	15.0	1.00	0.50	77.4	*	*	*	20	Weak repl. mineralization.
	AH-2-34	9	10	*	100	*	1,000	2.0	15.00	5.00	59.6	*	*	*	*	Weak mineralized repl. text.
	QC-6	5	300	10	1,000	2,000	1,000	33.0	1.50	0.20	37.9	*	20	*	*	Total Fe repl. bed.
	QC-7	12	50	*	50	200	2,000	1.0	26.00	5.00	1.7	1	*	*	*	Repl. text. - Same bed laterally as QC-6.
	DCA-1A-19 & 20	20	28	12	-	*	-	-	29.20	19.10	8.7	-	-	-	-	Weak repl. mineralization.
Bolsa Qtzite	QC-8	15	50	2	*	*	300	5.0	0.10	0.05	90.0	*	*	*	*	Weakly mineralized.
Dripping Spring Qtzite	AH-2-37	11	20	2	*	*	200	2.0	0.10	0.50	75.7	*	*	*	*	Weakly mineralized.
Manitou Granite	Z-4	grab	5	-	*	*	200	1.3	0.30	0.10	major	*	-	-	-	Fresh.
	Z-3	grab	8	-	30	*	200	1.2	0.30	0.10	major	*	-	-	-	Fresh.
	Z-2	grab	60	-	*	*	100	1.0	0.25	0.10	major	*	-	-	-	Fresh.
	Z-1	grab	5	-	*	*	100	1.2	0.25	0.10	major	*	-	-	-	Fresh.
Pinal Schist	A-2C-34	10	3,000	100	*	*	300	2.0	-	-	75.6	-	-	-	-	Wk. to strong argillic w/sulfide.
	A-2W-68	10	5,000	5	*	*	200	3.0	-	-	72.2	-	-	-	-	Qtz. & qtz. sericite w/sulfide.
	SC-1	grab	700	3	*	*	500	3.0	0.20	0.50	68.5	*	*	*	*	Cuttings from Churn Drill (sulfide).
	SR-11	grab	4,300	9	*	*	-	-	-	-	-	-	-	-	-	Moderate FeOx with transported copper oxides for SR samples.
	SR-12	grab	4,500	10	*	*	-	-	-	-	-	-	-	-	-	
	SR-13-2	10	420	41	50	*	-	-	-	-	-	-	-	-	-	
	SR-13-3	6	3,900	9	44	*	-	-	-	-	-	-	-	-	-	
	SR-13-4	10	1,400	6	36	*	-	-	-	-	-	-	-	-	-	
	SR-15	grab	2,800	2	*	*	-	-	-	-	-	-	-	-	-	
	SR-16	grab	4,500	9	*	*	-	-	-	-	-	-	-	-	-	

NOTE: Mineralization is Oxidized unless otherwise noted.

Dashed line (-) indicates no results for that sample. Generally signifies the other assays are by regular geochem (Atomic Absorption) and not by Emission Spectrography.

*Signifies results reported were less than 2 ppm Mo, or 25 ppm Pb, or 200 ppm Zn, or 1 ppm Ag, or 10 ppm Bi, or 50 ppm Cd, or 10 ppm Sn.

JDS Copy

ASARCO

Rocky Mountain
Exploration Division

July 10, 1978

TO: F.T. Graybeal

FROM: J.D. Sell

Replacement Limestone Assays
Queen Creek Area
Superior East Project
<u>Pinal County, Arizona</u>

As an additional calibration and for research purposes, seven samples were taken in the Queen Creek area by D. Krasowski and myself in the replacement textures and environment. The samples were submitted to ASARCO Salt Lake geochemistry for mercury analysis and Skyline Labs (Tucson) for emission spectrography and mercury analysis. Their report sheets are attached. The sample sites and numbers are shown on the MF-253 excerpt along with the vertical projection of Magma's Devonian horizon replacement body. This horizon tops out approximately <u>two thousand</u> feet below the surface at this point. Similarly, the Mississippian and Pennsylvanian ore body blocks also top out around 2500 feet below the surface and 2500-3000 feet <u>east</u> of the furthest western point on the Devonian horizon. (Note: The "A" designation indicates the sample was taken near or at the same sample site as reported in my memo of November 28, 1973, "Comparative Results - Emission Spectrographic Analysis, Superior East and Boheme Project Areas.")

As noted, the Skyline mercury values are very non-indicative whereas the SLC values have a range, and these have been added to the Skyline report.

Sample 1A was cut on a manganese-rich bed in the middle part of the Naco (Pennsylvanian) Limestone. The sample point would be on the south edge of the updip projection of the Naco body (located some 2500 feet below the sample point and 3000feet easterly). Silver is weakly anomalous (15ppm) while barium (200ppm), zinc (1000ppm), and mercury (105ppb) are anomalous. The original sample also ran 53,000ppm manganese and 76.0% silica which indicates its mineralization system. Low lead and copper values were associated with the sample.

Sample 2A was taken in a manganese-rich bed at the top of the Escabrosa Mississippian) Limestone and would also be on the southern edge as projected and some 4000 feet westerly and updip from the ore body block. Silver (200ppm), lead (1000ppm), zinc (5000ppm), and mercury (220ppb) are all anomalous in the horizon that contained 130,000ppm manganese and 37.7% silica (original sample). Copper again is a low value.

Two samples were taken along the LS & A vein structure which have no counterparts in the original sampling program. Sample 101 was taken about 45 feet above the karst surface in the Naco Limestone with only minor fracturing of the rock and very minor manganese-iron stain. Sample 102 was taken on the same structure and below the karst in the upper Escabrosa where manganese-rich mineralization and silica spread out from the vein and formed a mushroom of 20-30 feet of width. The sample is from the same horizon as QC-2A mentioned previously. Sample 101 (Naco) shows only anomalous silver (10ppm) and manganese (greater than 10,000ppm) values, indicating some leakage from the system going through the karst material. Sample 102 (Escabrosa) is very anomalous in silver (100ppm), barium (300ppm), lead (2000ppm), zinc (10,000ppm), and mercury (125ppb), as well as manganese (+10,000ppm) and undoubtedly silica. As noted, in comparison to a similar sample and horizon of QC-2A, the 102 sample has approximately twice the values noted. The LS & A vein system projects to be the second vein of bornite found in the breccia south of #9 shaft. This vein has not, to my knowledge, been checked eastward from the surface, nor tested underground when the replacement beds were exploited in the 1950's-early 60's.

Sample 3A is from the middle replacement horizon of the Escabrosa Limestone and in the wallrock of the original QC-3 sample. It is south of the LS & A vein and shows a weakly manganiferous addition but excellent replacement texture in outcrop. Although it does have 1500ppm manganese, no other values appear to be indicative that the sample site was within a mineralization pathway. (Whereas the original sample, cut on a small vein structure, contained 3000ppm lead, 3000ppm zinc, 200,000ppm manganese, and 24.5% silica with 50ppm silver.)

Sample 7A is the lower Martin Limestone replacement horizon and has excellent replacement texture with minor manganese. The values recorded are similar to the Escabrosa sample of 3A above.

Sample 8A is of the highly fractured and iron-stained Bolsa (Cambrian) quartzite underlying sample 7A. It contains about the same values as 7A except for an anomalous titanium (1500ppm) content probably reflective of the detrital magnetite grains and an anomalous mercury (135ppb) value.

Overall, in the Queen Creek area, it appears that we can see the plumbing system and leakage from the massive ore bodies mined (and to be found?) at a distance of 2000-3000 feet vertically and laterally (updip) by the use of silver, lead, zinc, mercury, manganese, and silica values. Closer to the ore bodies the increase in mercury, calcium and for magnesium should be apparent as wallrock additions.

James D Sell

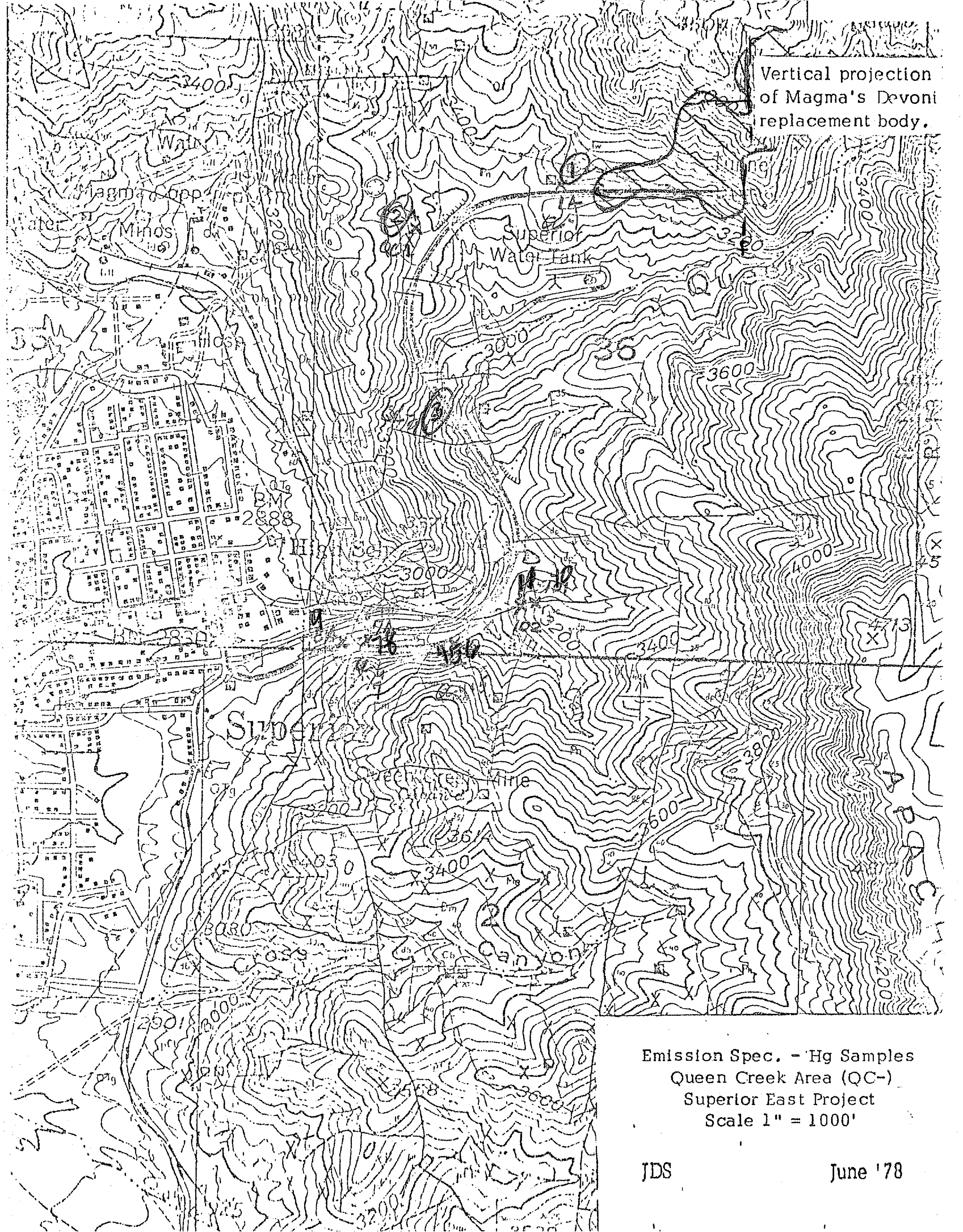
James D. Sell

JDS:slr
Attachments
cc: DMSmith, Jr.
DJKrasowski

ITEM NO.		SAMPLE NO.
1	=	QC-1A
2	=	QC-2A
3	=	QC-3A
4	=	QC-7A
5	=	QC-8A
6	=	QC-101
7	=	QC-102

ITEM	1 Naco repl.	2 Escalera, upper repl.	3 Escalera, mill repl. test, insufficient to original QC-3 sample.	4 Merilly house repl. test	5 Bolsa, Fe-stained	6 Naco, house, white	7 Escalera, upper, mushroom [illegible]
ELEMENT							
Fe	0.1%	0.5%	0.5%	0.5%	7%	0.5%	0.7%
Ca	3%	5%	>20%	20%	0.5%	>20%	0.2%
Mg	0.05%	0.05%	10%	10%	0.05%	0.1%	0.05%
As	15	200	1	1	1	10	100
Ag	<500	<500	<500	<500	<500	<500	<500
B	<10	10	<10	<10	10	<10	<10
Ba	200	<10	<10	<10	<10	<10	300
Be	<2	<2	<2	<2	<2	<2	<2
Bi	<10	<10	<10	<10	<10	<10	<10
Cd	<50	<50	<50	<50	<50	<50	<50
Co	<5	<5	<5	<5	<5	<5	<5
Cr	10	20	10	<10	150	10	70
Cu	100	200	10	30	500	20	200
Ga	<10	10	<10	<10	<10	<10	<10
Ge	<20	<20	<20	<20	<20	<20	<20
La	50	70	20	20	<20	30	20
Mn	>10000	>10000	1500	1500	1000	>10000	>10000
Mo	<2	20	<2	<2	5	2	15
Nb	<20	<20	<20	<20	20	<20	<20
Ni	5	5	<5	5	<5	5	7
Pb	70	1000	70	30	20	50	2000
Sb	<100	<100	<100	<100	<100	<100	<100
Sc	<10	<10	<10	<10	<10	<10	<10
Sn	<10	10	10	<10	<10	10	<10
Sr	500	300	<100	<100	500	200	200
Ti	50	70	20	50	1500	200	50
V	70	50	10	50	50	30	50
W	<50	<50	<50	<50	<50	<50	<50
Y	<10	10	<10	<10	<10	<10	<10
Zn	1000	5000	200	500	200	200	10000
Zr	<20	<20	<20	<20	100	<20	<20
Hg (SAC) ppb	105	220	45	45	135	65	125

SKYLINE LABS, INC.
SPECIALISTS IN EXPLORATION GEOCHEMISTRY



Vertical projection of Magma's Devoni replacement body.

Emission Spec. - Hg Samples
Queen Creek Area (QC-)
Superior East Project
Scale 1" = 1000'

JDS June '78

SKYLINE LABS, INC.
P.O. Box 50106 • 1700 West Grant Road
Tucson, Arizona 85703
(602) 622-4836

Charles E. Thompson
Arizona Registered Assayer No. 9427

William L. Lehmbeck
Arizona Registered Assayer No. 9425

James A. Martin
Arizona Registered Assayer No. 11122

CERTIFICATE OF ANALYSIS

ITEM NO.	SAMPLE IDENTIFICATION	Hg ppm		Hg ppb
1	QC- 1A	<0.01		<10
2	2A	<0.01		<10
3	3A	0.02		20
4	7A	0.01		10
5	8A	0.01		10
6	101	<0.01		<10
7	QC-102	0.01		10

TO:

ASARCO INCORPORATED
P.O. Box 5747
Tucson, Arizona 85703
Attn: James D. Sell

REMARKS:

Trace Analysis

CERTIFIED BY:

DATE REC'D: 2/2/78

DATE COMPL.: 6/27/78

JOB NUMBER: TAJ 091 Part 1

Project 78-41 ASARCO Page 1

GEOCHEMICAL DATA

Area
Date June 2, 1978
Requested By J. D. Sell, Tucson Office
No. Samples 7

AMPLE UMBER	Hg ppb
C-1A	105
C-2A	220
C-3A	45
C-7A	45
C-8A	135
C-101	65
C-102	125

11/1/78

FROM: F. T. GRAYBEAL

TO: All Geologists

A tentative field trip to the Superior-Inspiration area has been scheduled for the SWED for Dec. 5, 6, 7, and 8. I anticipate roughly one day of core review, one day of limestone replacement textures and outcrop, and two days of mine and prospect visits, hopefully including Magma, Pinto Valley, Inspiration, and Cactus Carlotta. Jim Sell is doing all the work (thank you, Jim).

F.T.G.

F.T.Graybeal

FTG:lb

cc: WLKurtz

ASARCO

Southwestern Exploration Division

November 30, 1978

TO: All Geologists

FROM: F. T. Graybeal

Superior Area Field Trip

I suggest the following distribution of riders and drivers with the drivers underlined:

Vehicle No. 1: JDS, WLK, PGV
Vehicle No. 2: SRD, HGK, GWP
Vehicle No. 3: GJS, FTG, NPW, BJD

The riders and drivers should make their own arrangements to assemble and should leave Tucson in time to arrive at the Superior Airport at 10:00 AM on Tuesday, December 5. The airport is located a few miles west of Superior immediately south of the main highway.

F.T. Graybeal

F. T. Graybeal

FTG:lb

cc: WLKurtz

ASARCO

Southwestern Exploration Division

JDS

November 22, 1978

TO: All Geologists

FROM: J. D. Sell

A field-trip excursion to the Superior-Miami-Christmas area has been arranged starting Tuesday, December 5, through Friday, December 8, with a possible extension into Saturday, December 9, 1978.

Accommodations have been reserved at the Copper Hills Motel, Miami.

As noted by the following schedule, limestone replacement, skarn, porphyry mineralization, and structure will be the main emphasis in the field and discussions.

Tuesday, Dec. 5: Load up three vehicles (drivers and distribution to be announced), then proceed and assemble at 10 AM at the Superior Airport, west of town. (Sketchy road log to be distributed.) Discussion of local geology and overview. Proceed to Queen Creek Canyon for examination of limestone replacement textures and mineralization related to the Magma-type mineralization. <u>BRING YOUR LUNCH</u> for sun and solace. View core, maps, and logs from SE Project in late PM.

Wednesday, Dec. 6: Underground tour of the replacement deposit, Superior Division of Magma Copper Company. Assemble at Magma's No. 9 Shaft (Oak Flat area), 8 AM. Initial geology-ore setting discussion by Magma Staff; underground tour with emphasis on development-mining techniques; possible incidental geology exposed behind lagging, etc. Bring available underground equipment, especially hard-toed boots, and change for shower after hot and dirty (?) tour. Probable late lunch with staff in Superior. Return to SE core shed in late PM.

Thursday, Dec. 7: Surface tour of skarn and diorite mineralization at Christmas open pit. Lunch somewhere--sometime. Follow-up on SE core in late PM.

Friday, Dec. 8: <u>Morning</u> tour of Pinto Valley mine geology. Lunch with tour staffs from Pinto Valley and Inspiration. <u>Afternoon</u> tour of Inspiration Pit area geology.

Possible return to Tucson late PM Friday, or may extend into Saturday, Dec. 9, for continued discussion of SE, Cactus-Carlotta, Power Gulch, et al, field geology, problems, and interpretation.

James D. Sell

James D. Sell

JDS:lb

cc: WLKurtz
FTGraybeal

ASARCO

Exploration Department
Southwestern United States Division

November 27, 1978

Mr. Charles G. Freeman, General Manager
Superior Division, Magma Copper Company
P.O. Box 37
Superior, Arizona 85273

ph. 689-2444

Dear Sir:

I wish to confirm that up to ten Asarco geologists will assemble at Magma's No. 9 Shaft at 8 AM, Wednesday, December 6, 1978, for a geology overview and underground tour with emphasis on the entire development-mining techniques practiced by your Division.

We will need some hard hats, safety glasses, etc., but will bring our own as available.

We would be pleased to have the tour leaders and yourself as our guests at lunch following the tour.

Sincerely,

James D. Sell

James D. Sell

JDS:lb

cc: FTGraybeal

ASARCO

Exploration Department
Southwestern United States Division

November 27, 1978

Mr. David S. Cook, Geologist
Inspiration Development Company
Inspiration, Arizona 85537

ph. 473-2411

Dear Sir:

I wish to confirm that up to ten Asarco geologists will meet with you for a conducted tour of the Christmas Mine area with emphasis on the skarn mineralization and related stock, on Thursday, December 7, 1978.

We will meet you at 8:30 AM at the IDC office in Claypool. We will furnish transportation for ourselves and have room for you and other leaders.

We would also be pleased to have you and the others as our guests for lunch, either interim or following the tour.

Sincerely,

James D. Sell

James D. Sell

JDS:lb

cc: FTGraybeal
Hugh Olmstead (IDC)
Jack Eastlick (ICC)

ASARCO

Exploration Department
Southwestern United States Division

November 27, 1978

Mr. G. E. "Sam" Napp
Manager-Operations
Cities Service Company
P.O. Box 100
Miami, Arizona 85539

ph. 473-4412

Dear Sir:

I wish to confirm that up to ten Asarco geologists will meet with your geologist(s) for a tour of the Pinto Valley pit and area geology on Friday morning, December 8, 1978.

We will meet at 9:15 AM at the Pinto Valley Mine office. We will have transportation for ourselves and the tour guides.

We would be pleased to have you and the tour leaders as our guests for lunch at the Copper Hills in Miami following the tour.

Sincerely,

James D. Sell

James D. Sell

JDS:lb

cc: FTGraybeal

ASARCO

Exploration Department
Southwestern United States Division

November 27, 1978

Mr. Jack T. Eastlick, Chief Geologist
Inspiration Consolidated Copper Company
Inspiration, Arizona 85537

ph. 473-2411

Dear Sir:

I wish to confirm that up to ten Asarco geologists will meet with you for a geology tour of the Inspiration Mine area on Friday afternoon, December 8, 1978.

We would be pleased to have you and others of your staff join us for lunch, around noon, say at the Copper Hills in Miami. We would then leave for the tour with your group.

We would furnish transportation with room for you and others.

Sincerely,

James D. Sell

James D. Sell

JDS:lb

cc: FTGraybeal

Inspiration Development Company
P. O. BOX 1320
CLAYPOOL, ARIZONA 85532

November 29, 1978

Mr. James D. Sell
ASARCO Inc.
P. O. Box 5747
Tucson, Arizona 85703

Dear Jim:

Thank you for your note confirming time and date for your group to tour the Christmas Mine. Everything as far as attendance, date and tour are fine. And I'll be pleased to join you for lunch.

I do, however, have one suggestion. If you are coming up from the Tucson area on the morning of the 7th, may I suggest that we meet at Christmas since you'll be driving right by it anyway. It'll save about 45 minutes driving time to Claypool and another 45 minutes return.

Of course, if you're not coming from Tucson, the meeting in Claypool is best. I'll be glad to confirm this with you via phone on Monday.

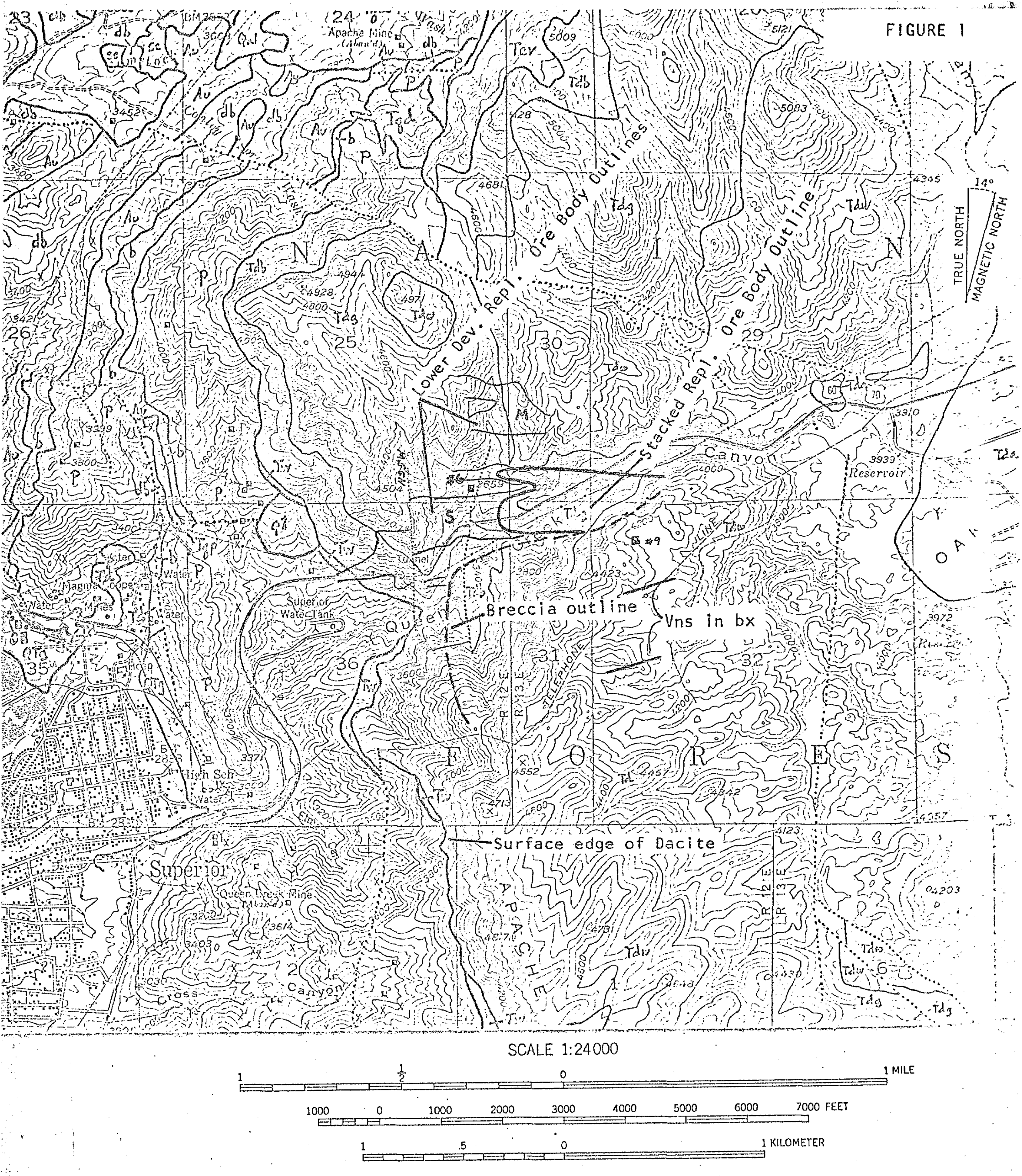
Sincerely,

Dave

David S. Cook
Sr. Exploration Geologist

DSC:cs

FIGURE 1


TRUE NORTH
MAGNETIC NORTH
14°
Lower Dev. Repl. Ore Body Outlines
Stacked Repl. Ore Body Outline
Breccia outline
Vns in bx
Surface edge of Dacite
P I N A L
F O R E S
A P A C H E
Apache Mine
Magma Copper Mines
Superior Water Tank
High Sch
Superior
Queen Creek Mine
Queen Creek
Canyon
Cross Canyon
Reservoir
Tunnel
#9
R 12 E
R 13 E
TELEPHONE LINE
23
24
26
25
30
29
35
36
31
32
2
1
6
Tdb
Tdg
Tdw
Tcv
Qal
P
Av
db
SCALE 1:24000
1
½
0
1 MILE
1000
0
1000
2000
3000
4000
5000
6000
7000 FEET
1
.5
0
1 KILOMETER
CONTOUR INTERVAL 40 FEET
DATUM IS MEAN SEA LEVEL

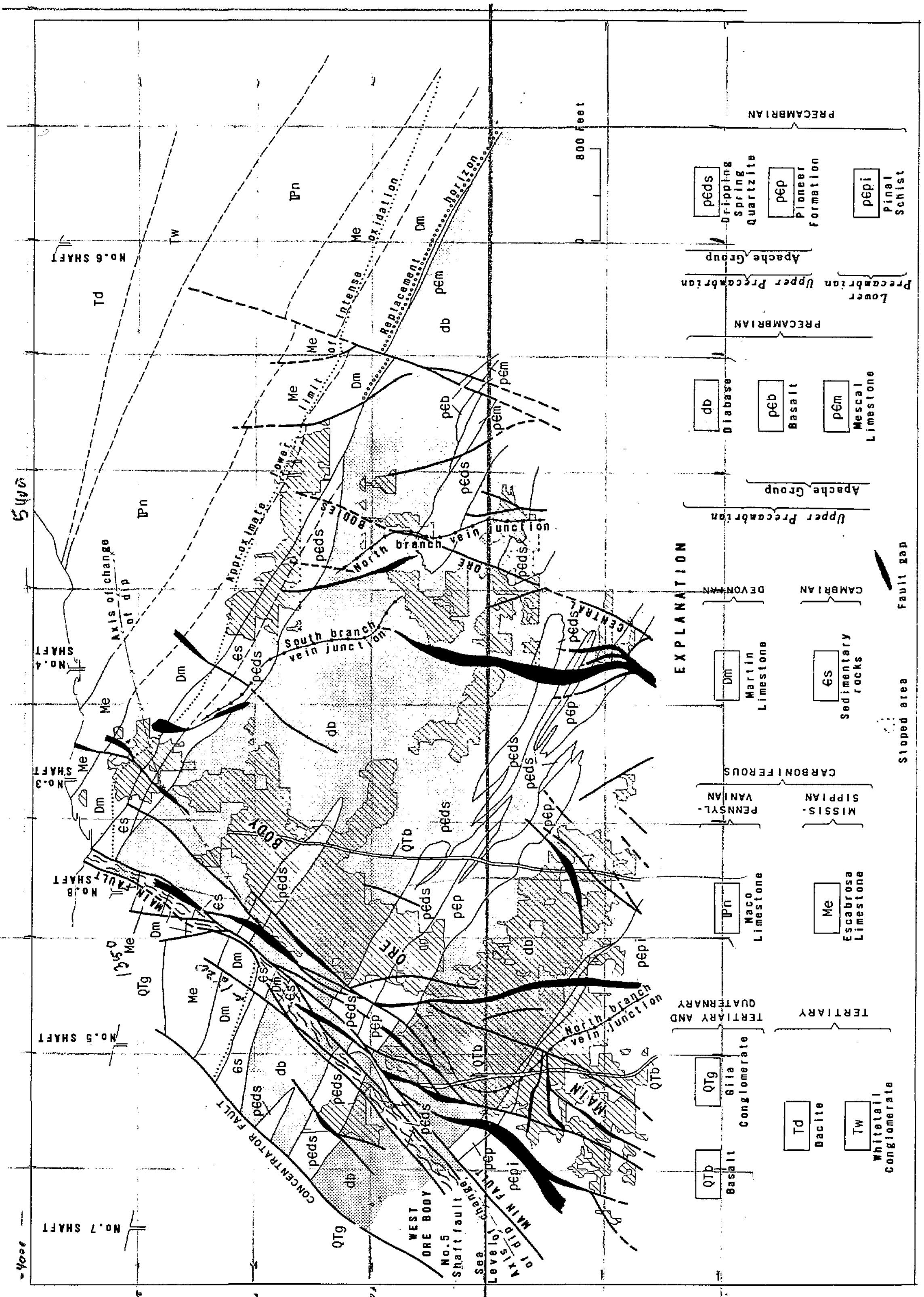


FIG. 3. *Geology of the South Wall of the Magma Vein. The Geology has been projected to a vertical, east-trending plane. Stoped areas, junctions of important branch veins, and axis of change of dip of the vein are indicated.*

---

side of the Main
has been stoped c
face to the 4900 l
is a smaller offset
that was mined or
fault between the
"Central ore bodic
continuous ore shc
in gross outline,
roughly parallel t
body. The Central
discontinuously fı
4800 level.

The Magma vє
fault zone that ha
10,000 feet along
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reversal of dip" (l
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continues downw
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Direction and ar
Magma fault zoı

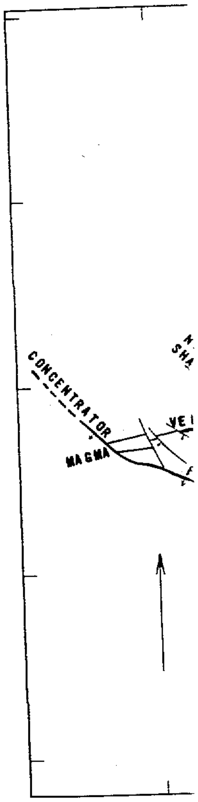
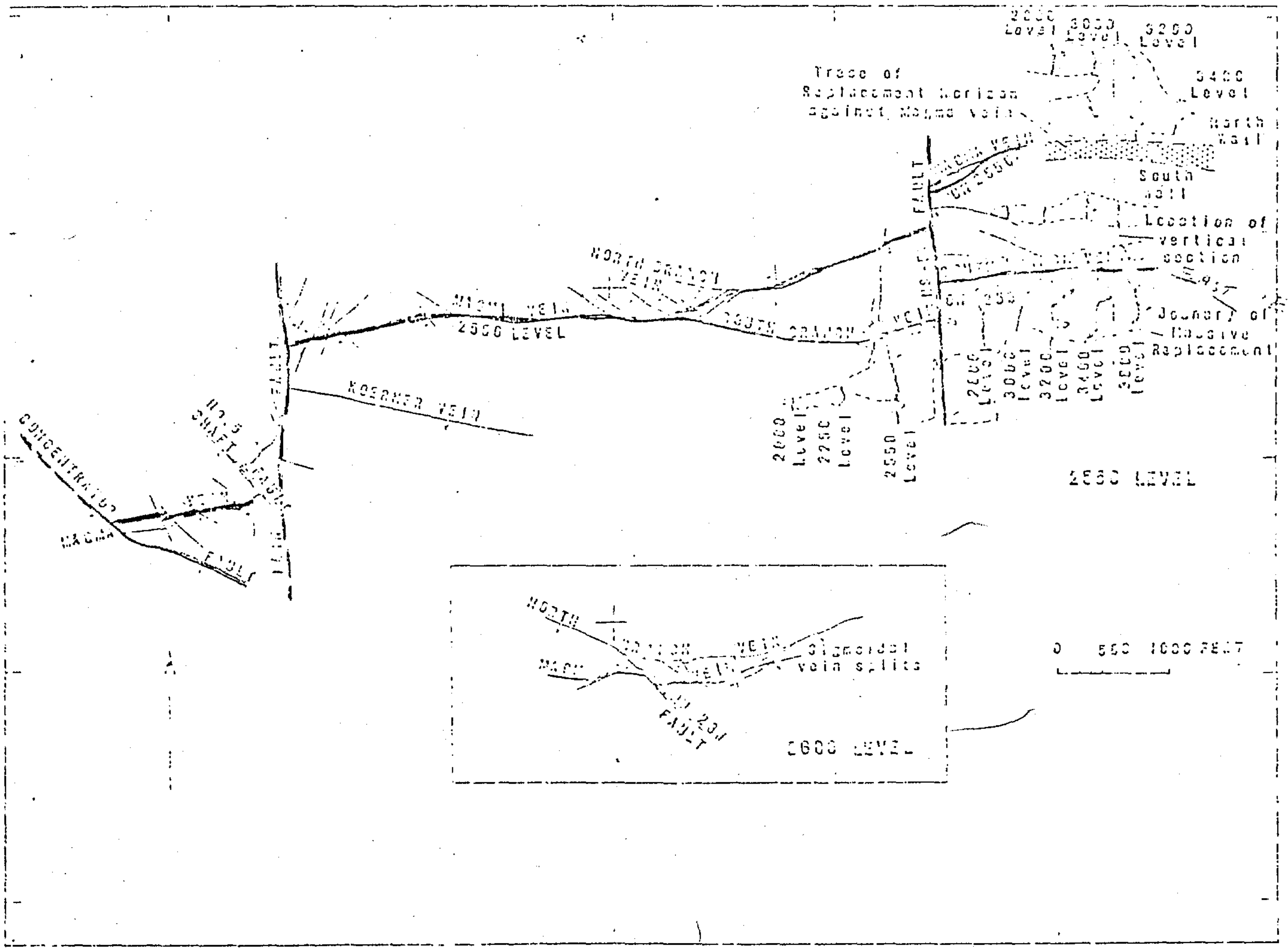


FIG. 4. *Structu*
its major bran
set, and the Kc
jected to the



3200' to 4

Collar 4300

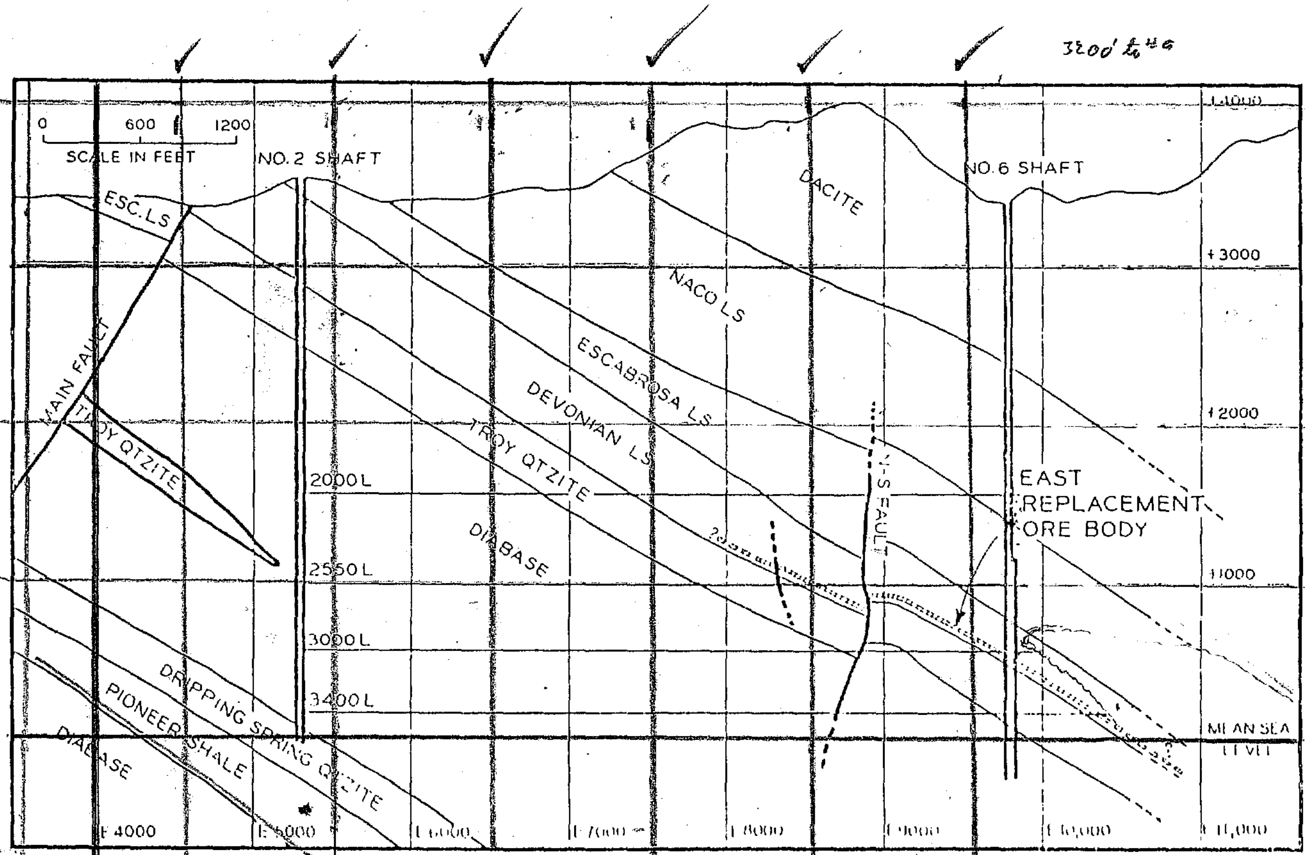


Fig. 2. East Replacement Orebody, east-west vertical section looking north.

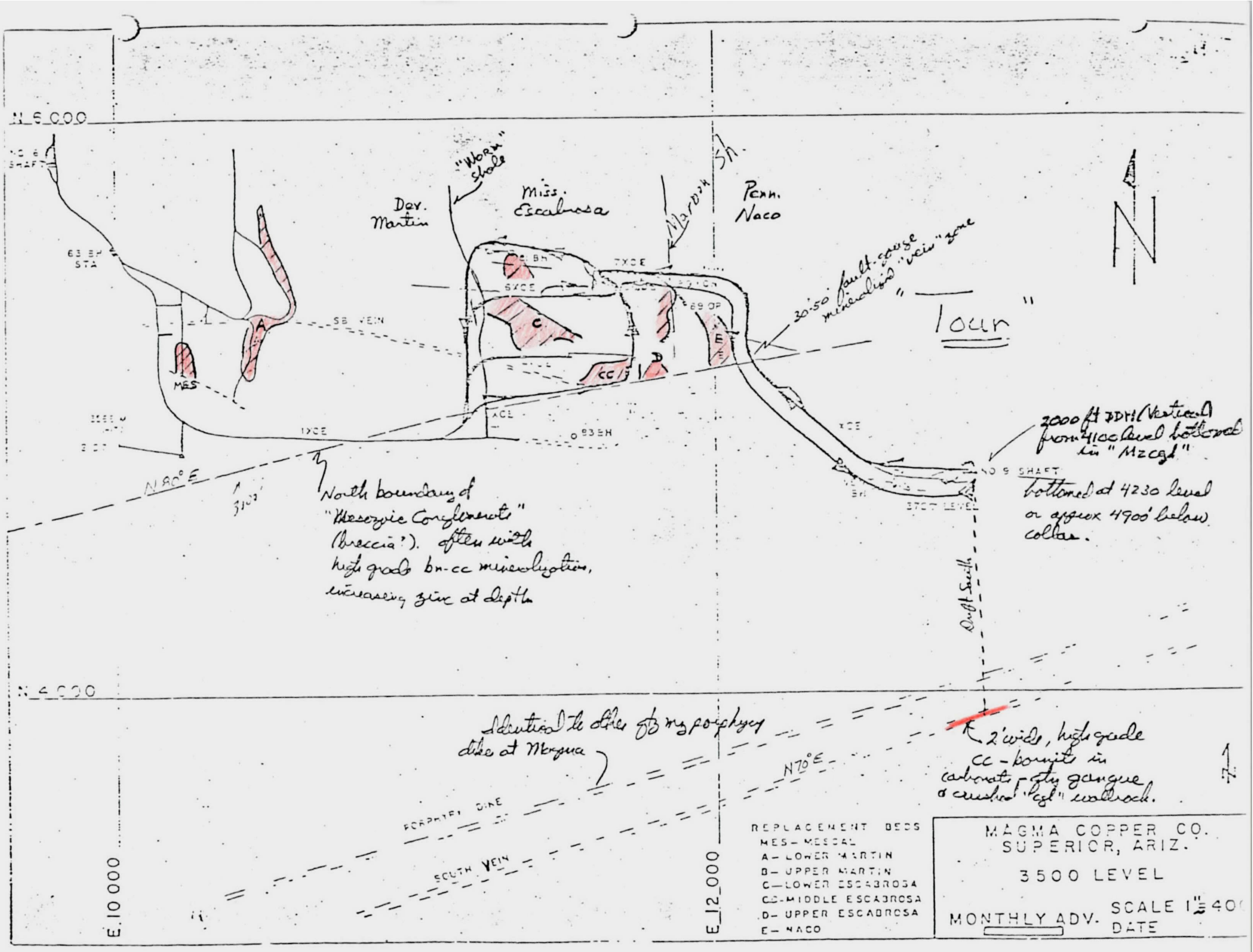
4250 level

ea

4900

Graton-Sales AIME Vol.

40 scal x2



"Tour"

30-50' fault-gouge mineralized "vein" zone

2000 ft DDH (Vertical) from 4100 level bottomed in "Mz cgl"

bottomed at 4230 level or approx 4900' below collar.

North boundary of "Mesozoic Conglomerate" (breccia?). often with high grade bn-cc mineralization, increasing zinc at depth

Identical to other qtz mz porphyry dike at Magma

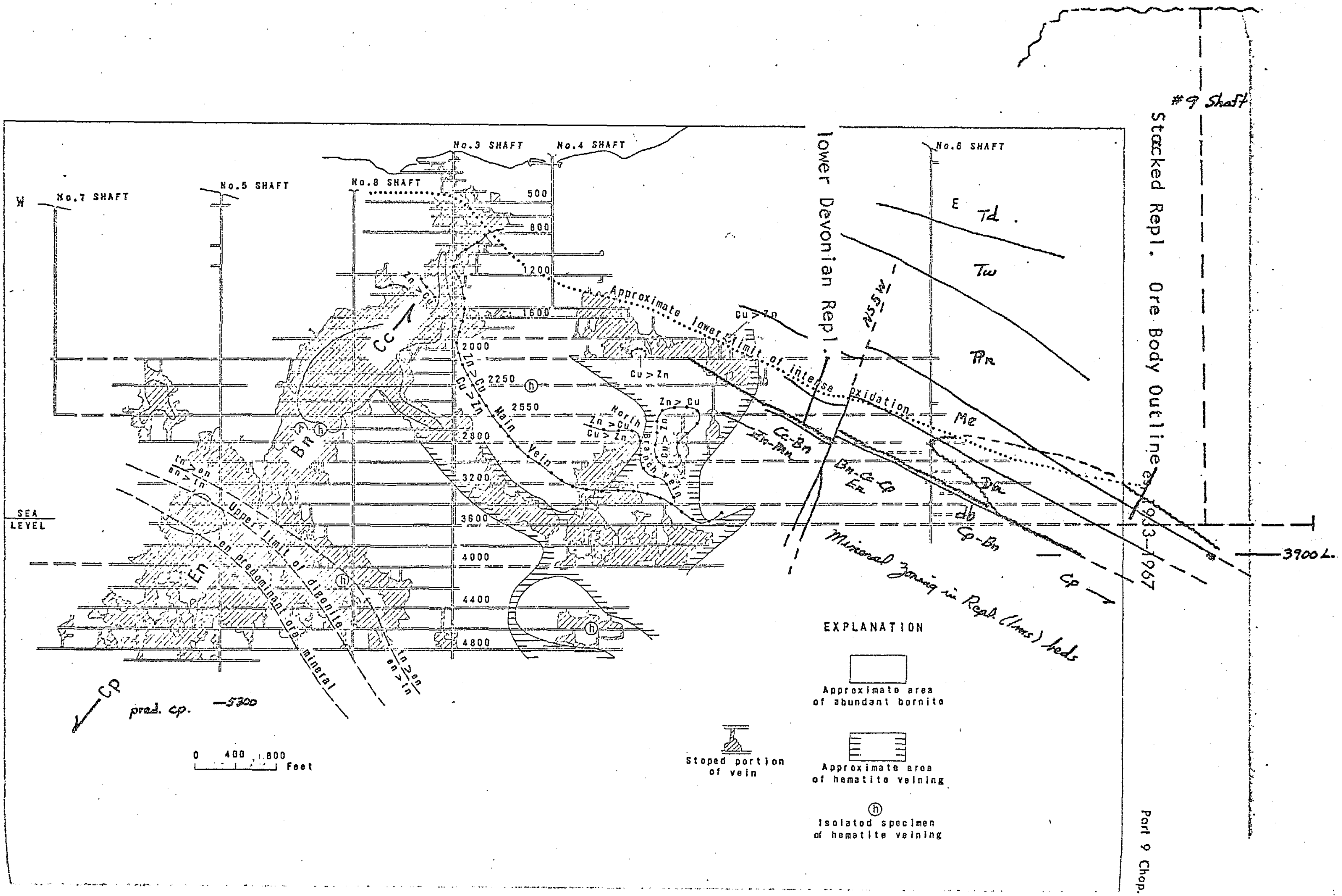
2' wide, high grade cc-bornite in carbonate-qtz gangue & crushed "cgl" wallrock.

REPLACEMENT BEDS
MES – MESCAL
A – LOWER MARTIN
B – UPPER MARTIN
C – LOWER ESCABROSA
CC – MIDDLE ESCABROSA
D – UPPER ESCABROSA
E – NACO

MAGMA COPPER CO.
SUPERIOR, ARIZ.

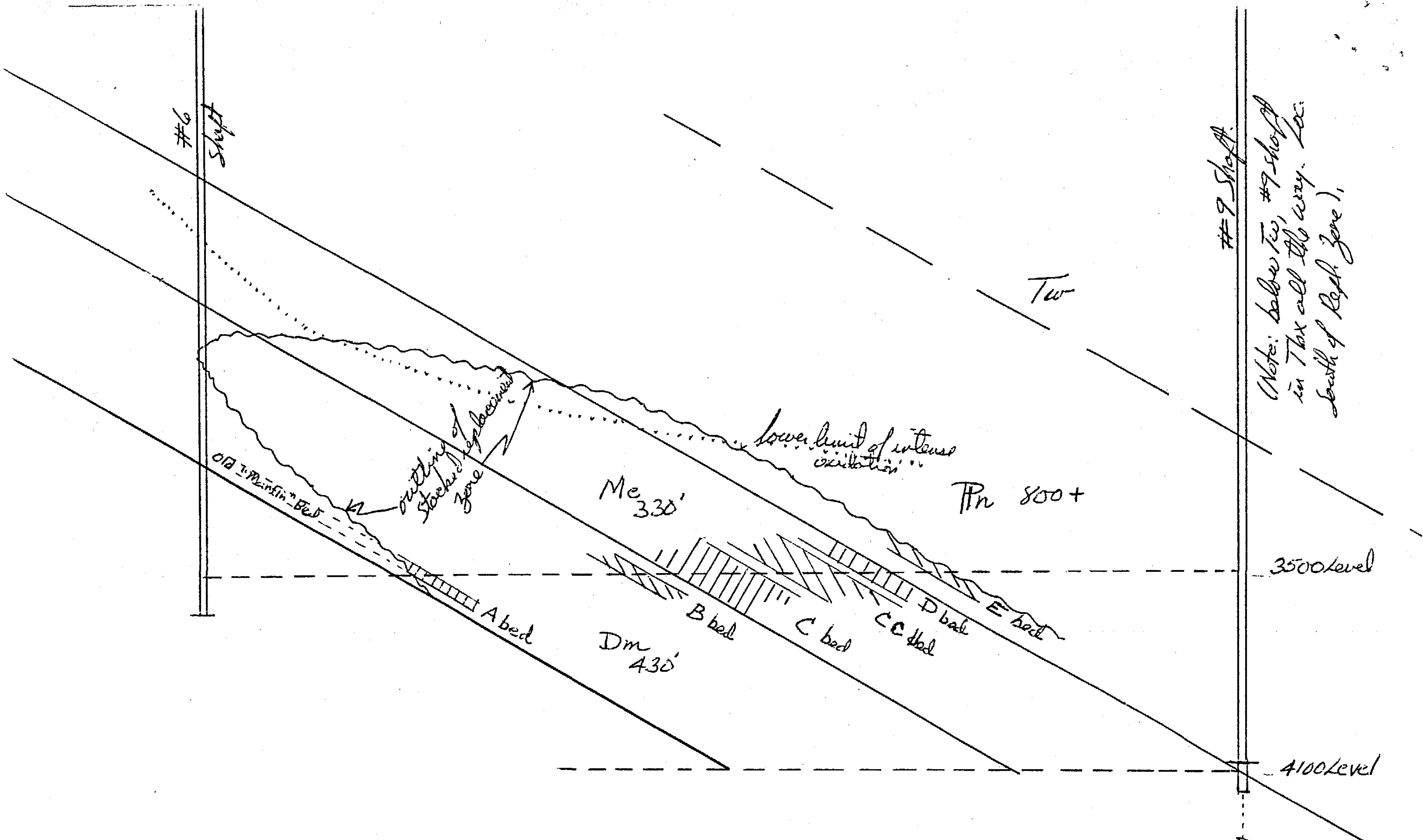
3500 LEVEL

MONTHLY ADV.
SCALE 1" = 40
DATE



Modified from Hammer (Graton-Sales Vol., AIME)

Fig. 5. Pattern of Mineral Zoning in the Magma Vein.



(Note: below Tw, #9 shaft in Tbx all the way. Loc. South of Repl. Zone).

2000' drill hole from bottom of shaft stayed in Tbx.

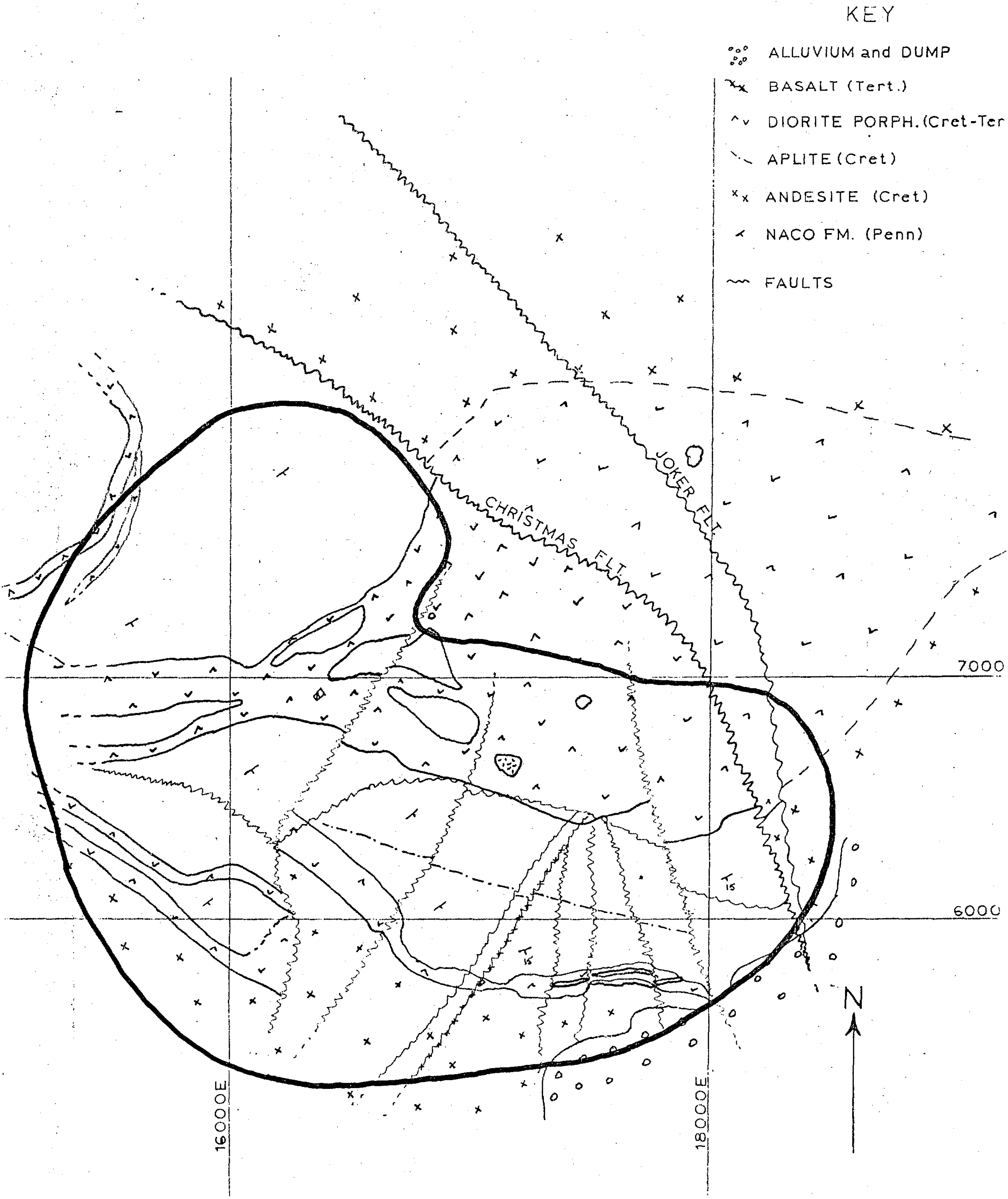
Stacked Replacement Ore Bodies
w/intense oxidation line after DFH.

E-W Section looking North
Thru #9 Shaft, units projected south
from Magma tour map of 3500 Level
1" = 400'

JWS 2/11/77

GEOLOGY OF THE CHRISTMAS MINE

SCALE 1" = 500'



ALTERATION AND MINERALIZATION OF IGNEOUS ROCKS AT CHRISTMAS MINE

SEQUENCE OF EVENTS

Intrusion and Stage I

Following deposition and greenschist facies alteration of the late Cretaceous Williamson Canyon Volcanics, the basaltic volcanic pile was intruded by a succession of Laramide calc-alkaline stocks, dikes and small plug-like bodies. In early Paleocene time (~62 m.y.), the Christmas intrusive complex was passively emplaced at shallow depth along east-northeast to east-west-trending fractures which formed in response to northeast-directed regional compression and differential uplift in southeastern Arizona (Rehrig and Heidrick, 1972, 1976).

The spatial configuration of the reconstructed Christmas stock-dike complex, viewed along a north-south cross section at approximately 18,000 E., is shown schematically in figure 10A. Seriate-porphyritic quartz diorite was intruded first, either as a thick tabular mass or a series of narrower, closely spaced dikes. Following at least partial consolidation, the quartz diorite was intruded and breached by numerous surges of biotite granodiorite porphyry, which in aggregate form the core of the complex. One or more pulses of magma ultimately migrated outward along the fracture zone to form rhyodacite porphyry dikes, and pushed outward into volcanic rocks to form the "northeast salient".

Intrusion of quartz diorite and granodiorite porphyry, K-silicate alteration, and associated chalcopyrite-bornite mineralization are believed to be broadly comtemporaneous features. K-Ar ages for Stage I vein minerals (table 2) are within error limits of the determined age of primary biotite from Light Phase. Early alteration-mineralization, however, did not evolve in a static system, but rather during a period of repeated surges of magma, particularly within the core of the stock.

Pervasive hornblende-destructive biotization, accompanied by precipitation of small amounts of sulfide and magnetite, occurred, at least in part, under late magmatic or "deuteric" conditions. Pervasive propylitic alteration in peripheral rhyodacite porphyry dikes may have been a contemporaneous process. K-Feldspar did not form with secondary biotite during deuteric alteration, but began to replace plagioclase along newly generated disoriented fractures. Thus, the plagioclase-destructive alteration appears to have been triggered by a rapid change in confining pressure. The random fine-scale brecciation within each intrusive phase and in superjacent volcanic rocks may have been generated by an internal process such as the explosive escape of volatiles during periods of retrograde boiling (Burnham, 1967, Phillips, 1973), or differential thermal expansion of pore fluids (Knapp and Knight, 1977).

Subsequently developed fractures, many with an apparent radial orientation were progressively more through going and steeply dipping. This change in fracture style, whether caused by external tectonic stress, the pressure of upwelling magma on consolidated rock, hydraulic action of hydrothermal fluids, or some other mechanism, coincided with the formation of increasingly quartz-rich, K-feldspar-poor veins. Although veins were becoming wider, K-feldspar envelopes remained narrow, suggesting that fluid and wallrock were in near chemical equilibrium. Although only minor amounts of chalcopyrite and, locally, molybdenite were deposited in the core of the complex, increasing quantities of chalcopyrite with bornite were precipitating in upper levels of the Stage I vein system, perhaps in response to a steeper temperature gradient. The presence of both primary and secondary gas-rich fluid inclusions in Stage I quartz veins indicates that boiling was a recurring event.

The direction of movement of Stage I fluids and geometry of early alteration-mineralization is shown in figure 10b. As potassic fluids emanating from the stock encountered the steep chemical gradient provided by basaltic volcanic rocks, K, Si, H, Cu and S were added during a nearly complete reconstitution to the assemblage biotite-quartz-sodic plagioclase-pale green amphibole-chalcopyrite-bornite-magnetite. The biotitic alteration and mineralization centered on the network of quartz-rich stockwork veins building upward in the volcanic pile. The distribution of strong biotization was further controlled by the configuration of genetically related intrusive rocks. Whereas a narrow zone developed along the steep south contact, a broad lobe of intense biotization formed over shallow apophyses of porphyry in the "northeast salient".

Stage II: Late Alteration

Following the formation of quartz-rich Stage I veins, a fundamental change occurred in the nature of fluid-wallrock interaction, as K-metasomatism declined in favor of processes that were predominantly hydrolitic in character. The mineral assemblages, distribution patterns of fracture-controlled chloritic alteration in mafic volcanic rocks, and sericitic alteration in felsic intrusive and feldspathic sedimentary rocks, and fluid inclusion populations in all types of Stage II veins suggest that these types of alteration resulted from the same hydrothermal process acting contemporaneously in host rocks of contrasting composition.

The transition to Stage II quartz-sericite-chlorite alteration, largely a function of decreasing K/H ratio and/or cooling of the hydrothermal fluids (Hemley and Jones, 1964; Meyer and Hemley, 1967), probably commenced with the first significant incursion of meteoric water into the porphyry system. The general model shown in figure 10c may reasonably account for the overlapping zonal distribution of Stage I and II vein-related alteration. This meteoric-hydrothermal model is similar to that proposed for porphyry copper deposits in general by Taylor (1974).

The flow of meteoric water was guided by an extensive system of fractures which were particularly abundant near the stock. A circulatory system may have evolved following the last major surge of magmatic-hydrothermal fluid from the cooling intrusive center. As cool meteoric waters and fluids from the magma began to intermix, sulfide solubilities decreased and pyrite and chalcopyrite were dumped along irregular fractures. Mg^{2+}/H^{+} ratios in the fluids were high enough and K^{+}/H^{+} ratios low enough to produce chlorite from earlier-formed secondary biotite. Fluids near the stock and the source of copper were depositing more chalcopyrite relative to pyrite than fluids in distal portions of the convection cell.

As the intrusive center continued to cool, the convection cell was drawn inward toward the stock resulting in overlap of Stage I and Stage II alteration-mineralization. Meteoric-hydrothermal fluids were able to penetrate the intrusive complex only along closely spaced vertical sheet fractures, leaching Ca, Na, and Fe from the wallrock, in exchange for H. The sheet fractures effectively channeled a volume of fluid large enough to permit expansion and ultimately, coalescence of vein envelopes. Since the outer limit of quartz-sericite alteration in intrusive rocks was also fracture controlled the zone of Stage II alteration developed in an intermediate position between zones of K-silicate and propylitic alteration.

The last minerals to form in chloritic veins in volcanic rocks were pyrite, chalcopyrite, and the Ca-zeolites, chabazite and laumontite. Experimental work by Liou (1971a, 1971b) suggests that at shallow depths and confining pressures of approximately 500 bars laumontite has a maximum stability limit of 225°C. Contamination of the fluid phase by CO2, S, and NaCl depresses the limit to lower temperatures. The high temperature stability limit for chabazite, although not yet established experimentally, would be somewhat lower (Liou, personal communication, 1977), and thus, the final deposition of sulfides may have occurred at temperatures near, or below, 200°C.

Following mainstage mineralization, granodiorite and dacite porphyry intruded the south margin of the stock with sharp contacts. These phases show no indications of K-silicate alteration, and they may not have achieved water saturation. Their temporal relationship with quartz-sericite-chlorite alteration is unknown. The chlorite-epidote alteration in these late phases is most reminiscent of the deuteric alteration prevalent in the McDonald stock northeast of the Christmas mine. However, disseminated bornite and chalcopyrite suggests that anomalous concentrations of metals and sulfur were present in the late-forming magmas.

77-79 my
Claremont
no skarn
in adjs.
Ans ?

Lo-epl beds: Was most widespread (1500' away from stock) & contains most reserves. gradation value away.
Miss dislocated & intruded blocks of very sharp cutoff to non skarn beds. (± 300' away from stock)
Perm. erratic but good values 50-300' away).

mag-garnet skarn
stock → bn-cp-sphal-fing.
Ag w/bn Au w/Cp.

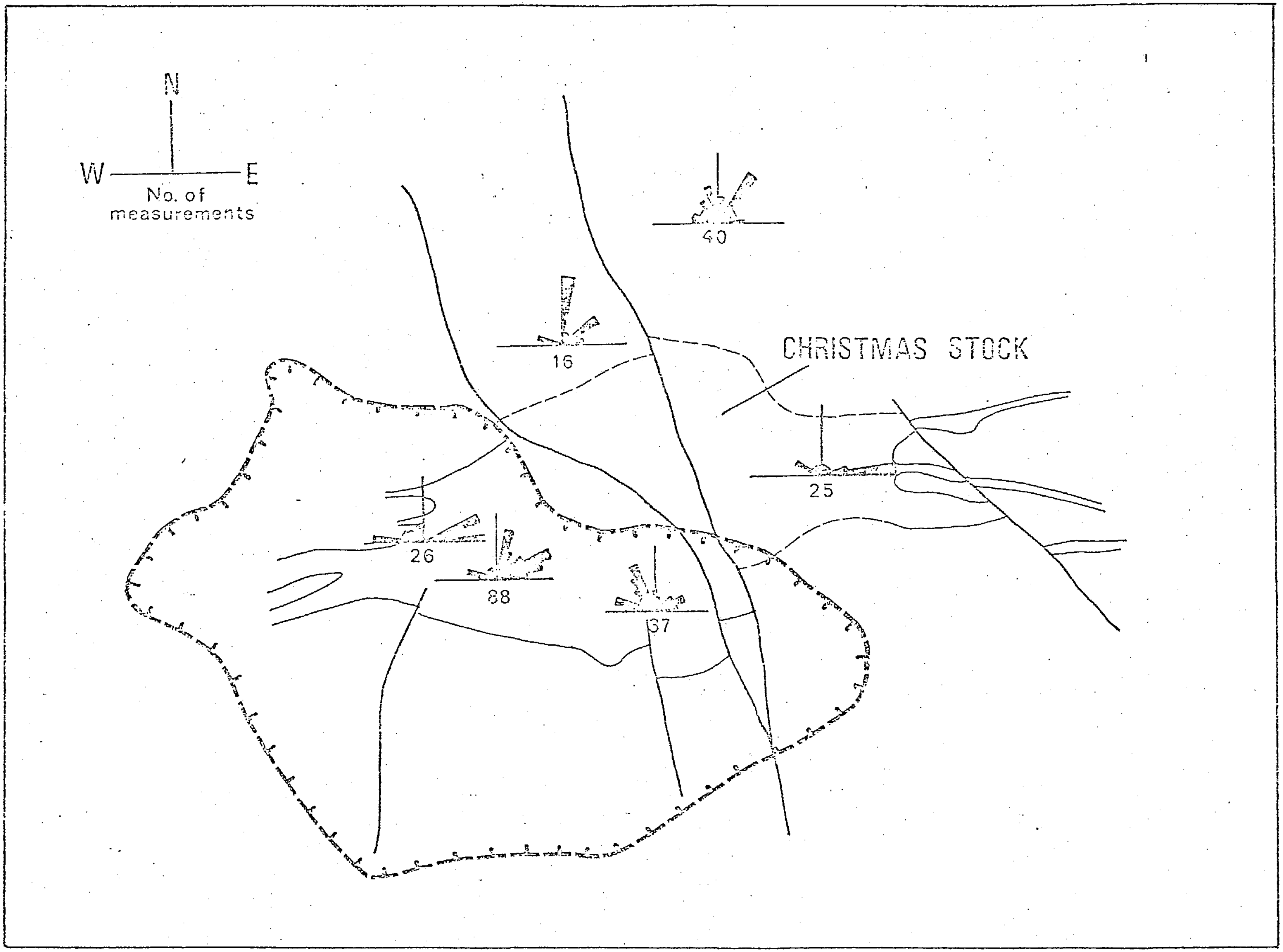


Figure 9. Strike histograms for Stage I veins cutting Light Phase, Dark Phase, and basalt within the K-silicate zone.

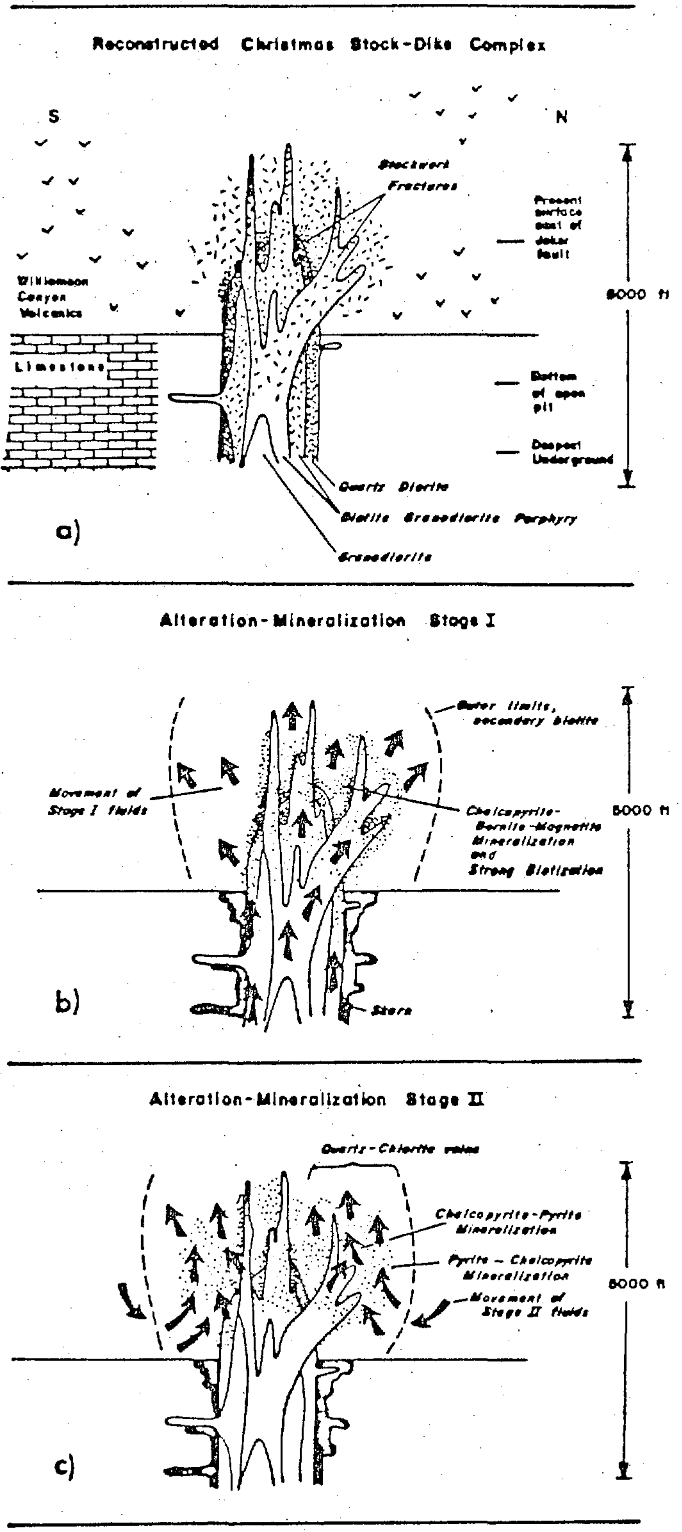
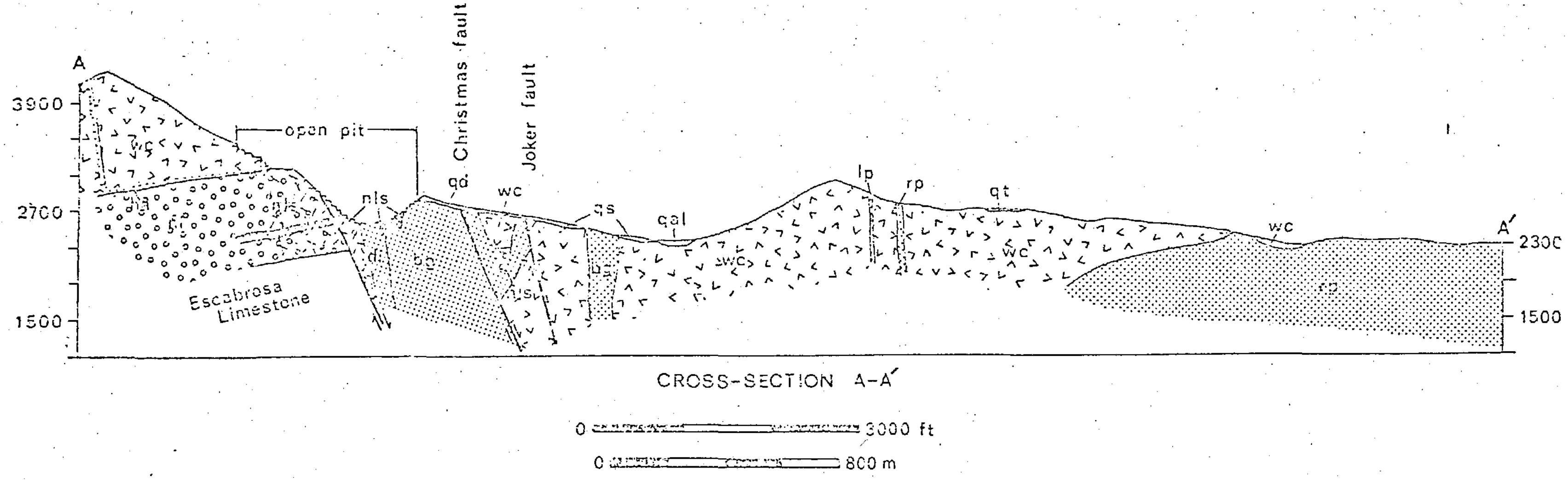


Figure 10. Diagrammatic configuration of the Christmas intrusive complex showing: a) general sequence of emplacement of major intrusive phases; b)Stage I alteration and mineralization; and c) convection model for Stage II alteration-mineralization. Arrows indicate movement of hydrothermal fluids.



Sedimentary and Volcanic Rocks

qd ▨ qt — Man-made surficial deposits
qd, dumps and roadfill
qt, tailings ponds

qs — qs, slope deposits

qal — qal, alluvium

wc wcs — Williamson Canyon Volcanics
wc, basalt
wcs, sedimentary deposits

nl — nl, Naco Limestone
nls, skarn

Intrusive Rocks

▒

lp, quartz latite porphyry

ap, aplite

fp, feldspar porphyry

Christmas Intrusive Complex
dp, dacite porphyry
gp, granodiorite porphyry
bg, biotite granodiorite porphyry (LIGHT PHASE)
di, quartz diorite (DARK PHASE)
br, biotite rhyodacite porphyry (dikes)

rp, hornblende rhyodacite porphyry (MACDONALD STOCK)

ha, hornblende andesite porphyry

Contact, dashed where concealed

Bedding

D U Normal fault, dashed where concealed;
U, upthrown side D, downthrown side

Figure 3. Geologic map and cross-section for the Christmas mine area.

TABLE II. Generalized Stratigraphic Section, Showing Igneous and Sedimentary Rocks in the Banner Mining District

Series	Formation	Thickness (in feet)	Character
Recent	Alluvium	100 ±	Gravel, sand, silt, clay, talus, and fanglomerate
Unconformity			
Tertiary	Gila Conglomerate	900 ±	Interbedded conglomerate, basalt, gravel, sand, sandstone, and gypsum, consisting of steam channel alluvium and lakebeds.
Unconformity			
Tertiary	Dikes		Narrow, generally N5°–25°W—trending olivine basalt dikes
	Dikes		Hornblende andesite dikes trend generally N50°–60°E to east-west.
	Dikes		Dacite porphyry dikes—trend generally east-west, intruding diorite bodies and sedimentary rocks.
	Breccia dikes		Narrow dikelike bodies of injection breccia with quartzite and shale fragments in a matrix of comminuted quartz or diorite.
	Stocks, plugs, dikes, and sills		Intrusive bodies of quartz hornblende diorite, quartz biotite diorite, quartz monzonite porphyry, and granite porphyry.
Cretaceous and/or Tertiary	Siliceous dikes and irregular masses		Irregular silicious dikes consisting of microcrystalline quartz and feldspar. Quartz mica diorite intrudes these bodies.
	Stocks, plugs, dikes, and sills		Fine grained diorite
Unconformity			
Cretaceous	Unnamed	2000'–3000'	Andesite, basalt, and pyroclastic rocks with intercalated shale and limestone
		5'–10'	5' to 10' conglomerate at the base of andesites near Christmas. Thickens to +1000' to the souhteast into a sedimentary sequence of conglomerate, siltstone, sandstone, and shale.
Unconformity			
Pennsylvanian	Naco Limestone (Upper member)	400 ±	Thick-bedded, light to dark gray crystalline limesatne wtih local chert nodules and thin shaly layers, containing abundant fusilinids.
	(Middle member)	500 ±	Thin to medium beds of limestone and shale, locally cherty, with abundant fossil fragments of crinoids, brachipods, and horn corals.
	(Lower member)	100 ±	Two beds of granular quartzite separated by thick bedded, gray, crystalline limestone in the upper 60 feet; fine to coarse grained crystalline limestone below with 5 feet of dark shale at the base.
Mississippian	Escabrosa Limestone	550 ±	Massive light gray, fine to coarse grained crystalline limestone; locally thin-bedded and cherty in the upper part.

Table II. Generalized Stratigraphic Section, Showing Igneous and Sedimentary Rocks in the Banner Mining District (Continued)

Series	Formation	Thickness (in feet)	Character
Devonian	Martin Limestone (Upper member)	65±	Thin-bedded shaly limestone, argillaceous and calcareous shales.
	(Middle member)	170±	Massive, light gray, fine grained crystalline limestone with thin quartzite beds in the upper part.
	O'Carroll bed	30±	Thin-bedded dolomite with interbedded limestone, shaoe, and shaly limestone at the base.
Unconformity			
Cambrian	Undivided	500	Calcareous and argillaceous quartzites with thin shales and limestone layers in the upper part; granuar quartzite with thin shale partings; angular conglomerate at the bottom.
Unconformity			
Precambrian	Troy Quartzite	900	Hard, dense quartzite and sandstone; pebble conglomerate at the base. Reassigned to Precambrian by Krieger (5).
Unconformity			
Precambrian (Apache Group)	Flow	50–75	Vesicular and amygdaloidal basalt
	Sills and irregular bodies		Diabase of several textural and compositional variations; intrudes all the rocks below the Troy formation.
	Mescal Limestone	250±	Sandy dolomites, cherty limestone, and marble
	Dripping Springs formation (Upper member)	75±	Tan to gray, fine grained, feldspathic quartzite; generally medium thick-bedded.
	(Middle member)	150±	Interbedded red-brown to gray quartzite and red shale
	(Lower member)	100±	Medium to thick bedded, gray to tan quartzite
	(Barnes Conglomerate member)	15–50	Well-rounded pebbles of quartzite and quartz in a matrix of arkosic sand. Reduced to rank of member. (Willden, 7, p. E 12)
	Pioneer Shale or Formation	200±	Reddish-brown to purplish shales, siltstones, and sandy silstolnes; characterized by numerous small oval greenish-gray spots.
	Scanlon Conglomerate	5–10	Well-rounded pebbles of quartzite and quartz in a matrix of arkosic sand. Reduced to rank of member (Willden, 7, p. E 12).
Unconformity			
Precambrian	Irregular bodies		Red to red-brown, coarse grained quartz monzonite; igneous rock similar in character and composition intrudes schist in the Tortilla Mountains to the south and in the Pinal Mountains to the north.

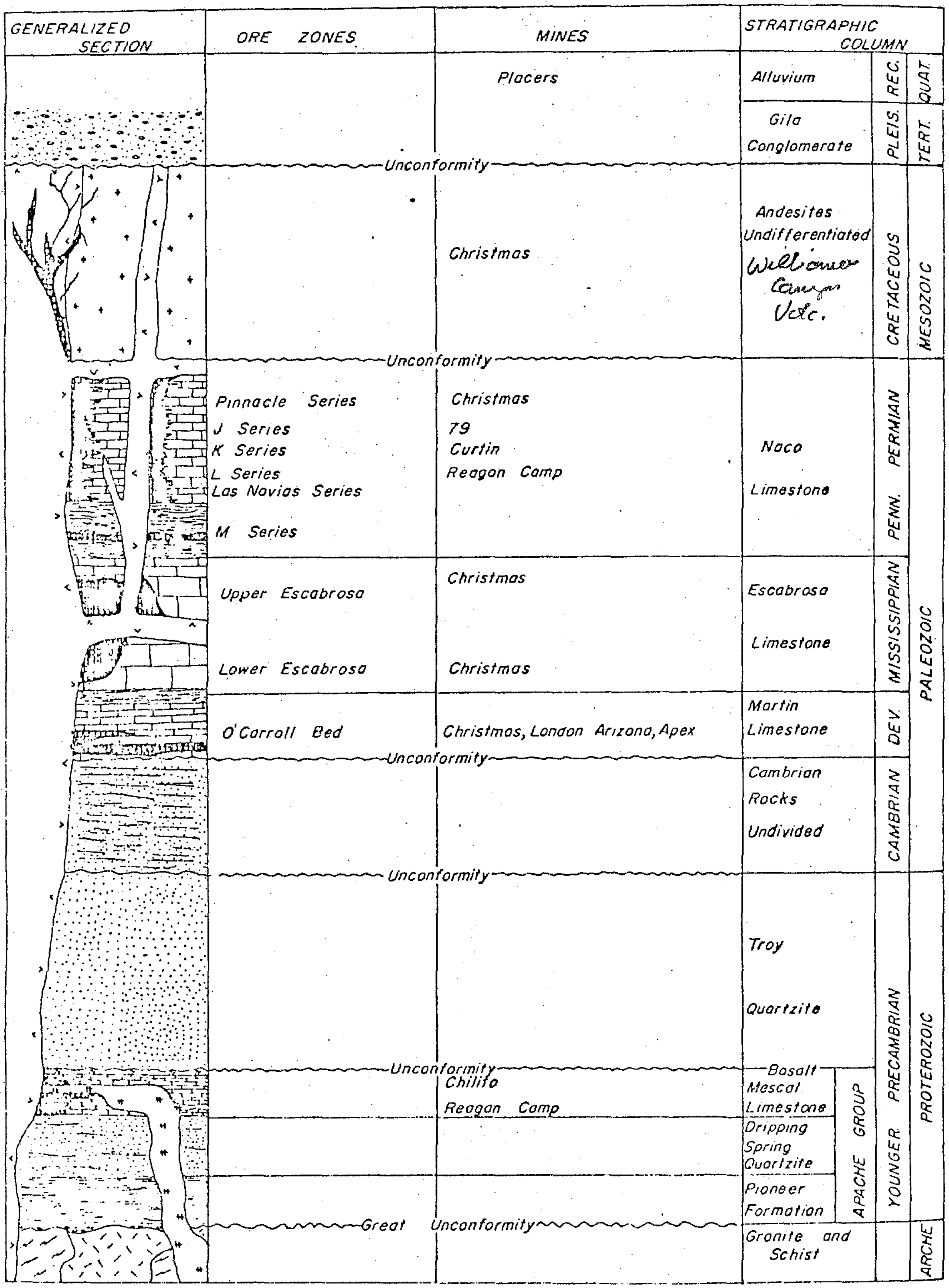


FIG. 4. *Correlation of Major Rock Units and Ore Zones, Banner Mining District, Arizona.*

Chilitos:

ICC portion ≅ 5 mill T @ 0.4-0.6 Cu w/ MoS_2 credits

KCC " ≅ 200 T mill @ 0.6

In NE "Salient Area" strong biotitization of intrusive & wall rocks of Williamson Volcanics contain around 450 million tons of 0.45% Cu. Some 40 holes drilled with deepest some 1700 feet.

Extends under townsite & the canyon to north next to mill & back to present pit –

INSPIRATION CONSOLIDATED COPPER COMPANY

CHRISTMAS DIVISION

MINING INFORMATION

Mining Method: Open Pit (7-Day-24 Hour)
(Underground Operations ceased in 1966)

Pit Slope: 1 to 1 (20 ft. benches with safety bench every 40')

Stripping Ratio: 5.0 to 1.0

Mill Capacity: 5,600 TPD

Recovery Method: Sulfide Flotation

Average Ore Grade: 0.60% Cu

Ore Reserves (lbs. of cu): Open Pit - 251,000,000 lbs.*
Underground - 567,000,000 lbs.*
(23 mill tons @ 1.8% Cu.

Equipment: Drills: 2 Robbins Rotary
1 Ingersoll-Rand Rotary

Trucks: 16 Caterpillar 769B 35 ton

Loaders: 7 Caterpillar 988 w/6 yd bucket

*Ore Reserves from 1975 Inspiration Annual Report

SOME MINERALS FROM CHRISTMAS

Mineral	Formula	Appearances
DIOPTASE	$Cu_6 (Si_6O_{18}) \cdot 6H_2O$	green prisms and balls
KINOITE	$Cu_2Ca_2Si_3O_{10} \cdot 2H_2O$	blue coatings and balls
STRINGHAMITE	$CaCuSiO_4 \cdot 2H_2O$	purplish coatings
RUIZITE	$CaMn(SiO_3)_2(OH) \cdot 2H_2O$	brown balls
JUNITOITE	$CaZn_2Si_2O_7 \cdot H_2O$	clear to purplish tabular
ROSASITE	$(Cu,Zn)_2(OH)_2(CO_3)_2$	bluish green malachite
CHALCOTRICHITE	Cu_2O	red fibrous
XONOTLITE	$CaSiO_3 \cdot H_2O$	white fibrous
WHALENITE	CuCa-silicate	blue fibrous
APOPHYLLITE	$KCa_4(Si_2O_5)_4F \cdot 8H_2O$	clear tetragonal coatings

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with depth to about 50 percent of hydrostatic pressure from about 70 to 141 m. Temperatures follow the boiling point curve adjusted for overpressure, and reach 203.4°C at hole bottom.

At the top of the section, 2.1 m of sinter overlies 17.4 m of glacially deposited, obsidian-rich sand and gravel. From 19.5 m to the hole bottom is rhyolite containing phenocrysts of quartz, sanidine, and plagioclase in a devitrified groundmass of finely intergrown α-cristobalite and alkali feldspar. Intense hydrothermal activity resulted in the alteration of existing material, particularly the glacial sediment, and the deposition of hydrothermal minerals in cavities, fractures, and within the groundmass. Quartz is the first deposited and most abundant hydrothermal mineral in the rhyolite. Other hydrothermal minerals include: α-cristobalite, β-cristobalite, opal, chalcedony, kaolinite, alunite, montmorillonite, illite, celadonite, chlorite, mixed-layer clays, zeolites (clinoptilolite, mordenite, analcime, wairakite, laumontite, and dachiardite), hydrous calcium silicates, K-feldspar, albite, calcite, fluorite, aegirine, blue-green amphibole, hematite, pyrite, and sphene. This assemblage is one of the most varied yet found in Yellowstone drill holes and reflects the location of Y-13 in a zone of intense upflow for a long time. The process of hydrothermal alteration and deposition is still continuing at the Y-13 site, although the rate of change is decreasing with time due to self-sealing by hydrothermal minerals.

TERTIARY VOLCANIC ROCKS OF THE MINERAL MOUNTAIN AND TEAPOT MOUNTAIN QUADRANGLES, PINAL COUNTY, ARIZONA

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The widespread distribution of Tertiary volcanic rocks in south-central Arizona is controlled in part by prevolcanic structures along which volcanic vents were localized. Volcanic rocks in the Mineral Mountain and Teapot Mountain quadrangles mark the site of a major northwest-trending structural hingeline. This hingeline divides an older Precambrian X terrane on the west from intensely deformed sequences of rock as young as Pennsylvanian on the east, suggesting increased westerly uplift. The volcanic rocks consist of a pile of complexly interlayered rhyolite, andesite, dacite, flows and intrusive rocks, water-laid tuffs, and very minor olivine basalt. Although the rocks erupted from several different vents, time relations, space relations, and chemistry each give strong evidence of a single source for all the rocks. Available data (by the K-Ar dating method) on hornblende and biotite separates from the volcanic rocks range from 14 to 19 m.y. and establish the pre-middle Miocene age of major dislocations along the structural hingeline. Most of the volcanic rocks contain glass, either at the base of the flows or as an envelope around the intrusive phases. One of the intrusive rhyolites, however, seems to represent one of the final eruptions. Intense vesiculation of the intrusive rhyolite suggests a large content of volatiles at the time of its eruption. Mineralization is associated with the more silicic of these middle Miocene volcanic rocks; specifically, extensive fissure quartz veins contain locally significant amounts of silver, lead, and zinc and minor amounts of gold. Many of the most productive deposits are hosted by the volcanic rocks, although others occur in the Precambrian rocks. Magnetic data correspond roughly to the geology in outlining the overall extent of the volcanic rocks as a magnetic low.

PATTERNS AND PROCESSES OF CONTINENTAL MARGIN SEDIMENTATION OFF PERU - GEOTECHNICAL PROPERTIES AND SEDIMENT STABILITY

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Geotechnical properties and stability characteristics of the continental margin deposits off Peru indicate that the upwelling process, which is pronounced in this area, is strongly imprinted on the underlying sediments. In comparison to other margin deposits, those beneath areas of upwelling possess considerably higher water contents, porosities, and sensitivities and lower wet bulk densities. Examination of a number of coastal areas indicates that as the intensity of upwelling increases, water content, porosity, and sensitivity also increase whereas wet bulk density decreases. Sediments in areas of intense upwelling off Peru are distinguished by water contents of 500-600% (by dry weight) with a maximum of up to 853%, bulk densities of 1.15-1.20 Mg/m^3 and a minimum of 1.09 Mg/m^3 and sensitivities commonly on the order of 10-15 but reaching as high as 21. Such sensitivities indicate that the stability of the Peruvian sediments is quite low, losing between 87 and 94% of their strength when disturbed, for example as might result from a seismic shock. The high productivity associated with upwelling results in increased organic carbon concentrations in the underlying sediments, a factor which seems to have a significant role in contributing to the unique characteristics of these margin deposits.

LATE NEOGENE CLIMATIC OSCILLATIONS ACROSS THE MID LATITUDES OF THE NORTH PACIFIC

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Major paleoclimatic/paleoceanographic oscillations across the mid latitudes of the North Pacific have been identified based on quantitative analysis of temperature sensitive planktonic foraminiferal biofacies at DSDP Sites 173, 310, and 296. In the marginal Northeast Pacific DSDP Site 173 temperature oscillations within the California Current system are marked by alternating cool and transitional faunal assemblages represented by fluctuating abundances of Neogloboquadrina pachyderma and coiling ratios. In the marginal Northwest Pacific DSDP Site 296 temperature oscillations within the Kuroshio Current system are characterized by alternating subtropical and transitional faunal assemblages represented by fluctuating abundances in temperature sensitive species of Globorotalia. In the Central North Pacific DSDP Site 310 subarctic, transitional and subtropical faunal assemblages are present permitting paleoclimatic/paleoceanographic correlations with the Northwest and Northeast Pacific sites. Frequency distributions of temperature sensitive planktonic foraminiferal species identify five major paleoclimatic cool events extending across the mid latitudes of the North Pacific. A major cooling occurred during the latest Miocene to early Pliocene. This period is followed by a short cooling at about 3.2-3.4 m.y. Warmer temperatures resumed during the late Pliocene followed by a cool period commencing at about 2.4 m.y. Warm but oscillating temperatures prevailed during early Pleistocene followed by a cooling at about 1.2 m.y. A further cooling is indicated during the late Pleistocene beginning at about 0.7 m.y. ago. Paleoclimatic interpretations based on frequency distributions of planktonic foraminifera are supported by oxygen isotope analysis.

GENERATION OF THE QUOTTOON PLUTON (BRITISH COLUMBIA) BY CRUSTAL ANATEXIS

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Field and petrologic investigation of the para-autochthonous Quottoon Pluton and the surrounding metasediments suggest that it has been generated locally by crustal anatexis. The major melt producing reactions involve incongruent melting of hydrous phases.

Pressure and temperature estimates of final metamorphic equilibration in the country rock are 750° ± 50°C and 4.9 ± .5kb. These estimates are essentially the same as for other localities in the regional granulite grade (orthopyroxene-plagioclase subfacies) metamorphism of the Central Gneiss Complex of the Coast Ranges. Textural evidence for anatexis includes resorbed biotite associated with inverse zoning of plagioclase and K-feldspar interstitial to quartz and plagioclase.

The Quottoon Pluton contains demonstratable igneous textures which include normally zoned euhedral plagioclase. Some normally zoned plagioclase crystals have distinct anhedral cores which are interpreted to be relicts of the protolith.

The geothermal gradient of 45° ± 5°C/km implied by the metamorphic assemblages suggests higher temperatures and consequently greater proportions of melt below the present level of exposure. For example, a temperature of 850°C at 6 kb is well into the region of experimentally determined incongruent melting of biotite. Thus the generation of the Quottoon Pluton is reasonably attributed to incongruent melting of biotite to produce amphiboles or pyroxenes plus melt at depths of 20 to 25 km followed by diapiric rise of the crystal-laden melt to about 15 km depth. Continued rapid uplift of the region is suggested by compositional zoning in garnet, low density $CO_2 + H_2O$ fluid inclusions, and nearly concordant K-Ar dates on biotite and hornblende.

IMPACT OF GULF COAST LIGNITE MINING ON GEOHYDROLOGY

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Reclaimed surface mines have geohydrologic properties that are significantly different from those of the undisturbed overburden, in that the permeability is significantly lower. At one test pit the permeability decreased from 10^{-2} cm/sec (pre-mining) to 10^{-5} cm/sec (reclaimed) because of mixing of overconsolidated shales and uncemented aquifer sands during mining. Laboratory tests show that the permeability decreases with load in a non-linear fashion, with the greatest variation with depth occurring in the upper 30 ft. Changes in permeability may 1) control the quantity of mine leachate moving into down-dip aquifers, and 2) impact the geohydrologic balance of near surface aquifers. This study suggests that: 1) acid mine-water formation and leaching will occur near the surface,
2) deeper acid water formation and leaching may be minimized,
3) effects of acid mine leachate may be localized, 4) mixing of stratified materials will destroy shallow aquifers, and 5) because 80% of the total mine settlement occurs within 5 years, the new geohydrologic system will be established within the mine operators' period of liability.

THE HAT CREEK COAL DEPOSIT: A GEOPHYSICAL CASE HISTORY

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The Hat Creek Valley encloses one of the world's largest known coal deposits. The coal response to magnetics, electromagnetics, induced polarization, various downhole logging techniques and gravity surveys are examined.

The magnetic method was used for field mapping of geological units and was particularly useful in detecting volcanic rocks. Electromagnetic methods detected conductive fault zones with varying degrees of success, while an induced polarization survey gave poor results because of the scarcity and habit of polarizable minerals in the deposit. Downhole logging techniques were used to correlate geologic units between drillholes.

The gravity method directly detected the low density coal and yielded one of the world's largest recorded gravity anomalies over a body of economic importance. Analysis of the gravity data indicates a faulted coal deposit of variable width and depth, extending continuously for 12 miles. Possible coal reserves are estimated at 17-20 billion tons.

THE KAPITEAN (LATEST MIOCENE) PALEOCLIMATIC EVENT IN THE SOUTH PACIFIC

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Late Miocene planktonic foraminiferal sequences and oxygen isotopic stratigraphy have been examined in several DSDP sites in the South assemblages are associated with mineralization.

Porphyry-Type Mineralization

In 1973, an alteration study of the San Manuel -Kalamazoo porphyry deposit was initiated for the purpose of projecting future ore reserves at the mine site, and establishing trends in alteration to assist in exploration of surrounding areas (Figure 1). Geochemical and x-ray diffraction data from over 800 whole rock samples from 72 diamond and churn drill holes (and mine samples) were plotted and contoured on multiple sections through the two segments.

The San Manuel ore body is located below the footwall of the San Manuel fault, updip and nearly a mile northeast of the Kalamazoo deposit.

Alteration associated with the San Manuel segment was investigated from one longitudinal section, two cross sections, and one horizontal section through the ore body at the 2075 Haulage Level (Figure 2). In plan, the ore body is U-shaped, with the open end oriented toward the Kalamazoo segment (Figure 3). Concentric envelopes of sericitization (Figure 4), silicification (Figure 5) and pyritization (Figure 6) surround the ore body, displaying the same shape and orientation as the ore. Alteration contours are closed on all sides except toward Kalamazoo, suggesting that economic mineralization may be terminated on all sides except to the southwest at this level.

Copper assays are also plotted and contoured in cross section (Figure 7), showing the north (AB) and south (CD) halves of the ore body. Contour intervals are 0.6, 0.3, and 0.1% Cu, analogous to Kalamazoo. If the two halves were composited, the ore body would appear as a tilted U-shaped configuration, with the open portion of the "U" oriented upward towards the west.

Contours of decreasing copper mineralization are generally smooth and uniformly spaced, indicative of gradational changes away from the ore zone, with the exception of the eastern perimeter of the deposit where a relatively wide zone of low grade copper (0.1-0.2% Cu) persists to the east for an indeterminant distance. This greater thickness of low grade copper is associated with greater thicknesses of alteration, and may be related spacially to the sharp flexure (or greatest curvature) of the "U".

The San Manuel ore body is surrounded by concentric zones of alteration, similar to Kalamazoo except that the zoning is inverted in relation to Kalamazoo, following the underside of the San Manuel ore body, e.g., sericitization (Figure 8), silicification (Figure 9), pyritization (Figure 10) and feldspar "low" (Figure 11). This evidence favors Lowell's conceptual "cylindrical" model for the Kalamazoo and San Manuel segments. A composite reconstruction of the two segments indicates that the ore shell consists of an elliptical cylinder (Figure 12), surrounded by alteration.

The ore body in longitudinal section is "canoe-shaped," plunging gently to the west, locally segmented by steeply dipping normal faults to the east, and largely terminated by the Hangover fault on the west (Figure 13). A major flexure in the ore body occurs at the eastern end, where the contours swing upward and roll back toward the west at higher elevations.

Concentric halos of sericitization (Figure 13) as well as silicification, pyritization and feldspar "lows" surround the ore shell on all sides, except the interior core of the deposit, which plunges to the southwest. Halos of alteration thus define the trends of mineralization on the east, bottom, and partially along the top (near the east end), reflecting the shape and symmetry of the ore zone. Alteration contouring indicates that the San Manuel ore body is terminated circumferentially and on the east by closed contours, but remains open to the west and on top, where the Kalamazoo segment is believed to have been removed.

Drill hole locations for two of the sections through the Kalamazoo segment are given in (Figure 14), showing in plan the cross section AB and longitudinal section CD. Copper assays are plotted and contoured in cross section AB (Figure 15) showing the general configuration of the Kalamazoo ore body (>0.6% Cu) and the outer halos of decreasing copper mineralization. (Contour intervals selected were 0.6%, 0.3% and 0.1% Cu.) The ore body is essentially crescent-shaped and convex upwards in cross section, with contours of decreasing copper mineralization generally conformable above and below the ore shell.

Cross-sectional plots of alteration data across the Kalamazoo segment show that sericitization (Figure 16), silicification (Figure 17), pyritization (Figure 18), and a feldspar "low" (Figure 19) occur as concordant blankets overlying the ore, conformable to the ore body. K-feldspathization (expressed as K-feldspar-plagioclase ratios) follows the ore zone proper (Figure 20). Alteration extends vertically above the ore for distances of 1000 to 2000 feet, locally intersecting the surface.

No fig 2

An integrated picture of the unsegmented ore shield is shown in a composite perspective drawing of the Kalamazoo and San Manuel segments in Figure 21. The pieces of the puzzle fit together in the integrated model, where both mineralization and alteration contours join spacially and geometrically, thus explaining the inverted alteration zoning at San Manuel compared with Kalamazoo, and confirming the cylindrical model for the Kalamazoo-San Manuel deposit.

Fig 21 [illegible]

With the firm knowledge of this relationship between the Kalamazoo and San Manuel segments, it becomes apparent that major mineralized trends (and limits) have been defined by alteration contours, and that the chances for discovery of additional significant tonnages of ore do not appear favorable without the association of these zones of intense alteration.

Stratiform Replacement (Mantos) Deposits

Features of geochemistry and alteration surrounding stratiform "mantos" replacement bodies of copper mineralization in Paleozoic limestones were investigated at the Magma Mine, Superior, Arizona. Replacements of chalcopyrite and bornite, associated with pyrite and hematite, occur along permeable dolomitic horizons in the Martin ("A" and "B" beds), Escabrosa ("C", "C-C" and "D" beds) and the Naco ("E" bed) replacement horizons (Figure 22). Each replacement horizon is surrounded by a calcitization alteration front,

[illegible] A 22

consisting usually of replacements of calcite in dolostones and dolomitic limestones.

Cherty silicification, chlorite and talc occur as low temperature replacements of dolostones along fringes of sub-economic mineralization (10' to 100' or more from ore). Relic magnetite has been identified along the east-west extremities of replacement horizons.

Representative sampling of the Escabrosa and Martin formations was difficult because of skeletinized cores and varying directions of angle holes. Further complexity was caused by local offsets in contours of alteration and geochemistry by east-west faults (pre- and post-mineral). Significant trends were nevertheless indicated, in the form of symmetrical halos of calcitization above and below each replacement horizon and replacements of talc, chlorite, quartz, hematite and magnetite associated with anomalous distributions of mercury, zinc, manganese and sulfur around each ore body.

Mineralization (and alteration) extend for much greater distances along permeable replacement horizons than across bedding normal to replacement horizons. Sampling in this study was relatively sparse at greater distances updip and downdip from ore bodies along replacement horizons, and for this reason, additional sampling is required to evaluate the extent of alteration and anomalous geochemistry at greater distances along these horizons. Nevertheless, preliminary information on the distribution of alteration around replacement horizons at Superior has provided useful guides in the evaluation of deep exploration drilling in other areas of potential replacement mineralization in the district.

Volcanogenic Massive Sulfide Deposits

Although volcanogenic deposits appear to differ in genesis from porphyry and mantos-type deposits, alteration minerals and geochemistry are similar. Alteration features, e.g., bleaching, chloritization, silicification and sericitization have been described by many investigators of volcanogenic deposits of the Canadian shield and similar deposits elsewhere in the world. Zones of alteration are commonly found in the footwall of these deposits, associated with crosscutting alteration pipes which are considered to mark the paths of mineralizing hydrothermal fluids of a fumarolic or hot spring nature that led to the deposition of massive sulfides in sea-floor environment.

Parameters of wallrock alteration and anomalous geochemistry have been identified at several volcanogenic deposits including Mattabi, Mattagami, Kidd Creek, Normetal and others, all of which show remarkably similar features of alteration.

Alteration is related to sulfide deposition, transecting a variety of different rock types, including dacites, rhyolites, andesites, cherts and agglomerates. An examination of rock types in the vicinity of the Mattabi massive sulfide deposit indicates extensive alteration in the form of silicification, sericitization and chloritization.

Silicification is visually apparent in outcrop in the form of chert bands and lenses of finely crystalline silica that locally display bedded features, but may also transect different rock types. Highest intensity of silicification appears to be superimposed over the ore zone proper (Figure 23), with values decreasing symmetrically on either side away from ore. Percentages of quartz decrease from about 70-80% within ore to around 50-60% in dacites and agglomerates immediately north and south of the ore zone, and finally down to 30-40% quartz at distances up to 200-400' from the deposit.

Sericitization is visually manifest in outcrop by bleaching and strong foliation. Highest sericite (10-20%) was detected in samples collected immediately adjacent to the deposit (Figure 24). This is best illustrated just north of the ore body where frequency of sampling makes possible a closed interval of contouring, showing an elongate shell of high sericitization just outside of the ore zone. This zone appears to extend from 100-200' away from the ore.

Chloritization occurs in all rock types in varying concentrations, depending on composition of rock and distance from ore. Minimum chlorite was usually detected in most cherty rocks within the deposit, increasing progressively in wallrocks north and south away from the ore zone, particularly in the agglomerates, where concentrations up to 30% were determined.

A variety of carbonate minerals were detected in altered rocks at Mattabi, including dolomite, siderite, ankerite and calcite. Dolomite is relatively abundant (up to 15%) in select samples of hanging wall dacite, whereas siderite and ankerite are more abundant in footwall agglomerates.

The bilateral symmetry of alteration features in the hanging and footwall rocks at Mattabi is strongly suggestive of epigenetic forms of alteration, the intensities of which may be contoured to delineate mineralizing trends.

Alteration studies of other volcanogenic deposits now in progress include Sherritt Gordon's Fox and Ruttan Lake deposits in Manitoba and select occurrences in the Bathurst district of New Brunswick.

Volcanogenic occurrences in the Bathurst district are associated with mineralized iron formations and highly sericitized augen schists. Alteration features associated with anomalous iron formations (BIF) are pre-tectonic in the Bathurst district, and affected by post-mineral dynamic changes, requiring specialized methods of exploration, including XRD analysis of whole rock samples and monomineralic contouring to supplement more conventional geochemical, geophysical and geologic data.

Conclusions

Techniques for the mineralogic contouring of alteration data are finding wider application today as a means of evaluating wallrock alteration. Special care is required to obtain reproducible XRD data, by means of fine grinding, Peter's grid and sample rotation during analysis.

Use of quantitative alteration data offers an alternative guide to geochemistry, and supplements the interpretive use of such terms as "propylitic," "phyllic," "potassic," "argillic," etc., which depend somewhat intuitively on the qualitative (and subjective) judgement and experience of the observer.

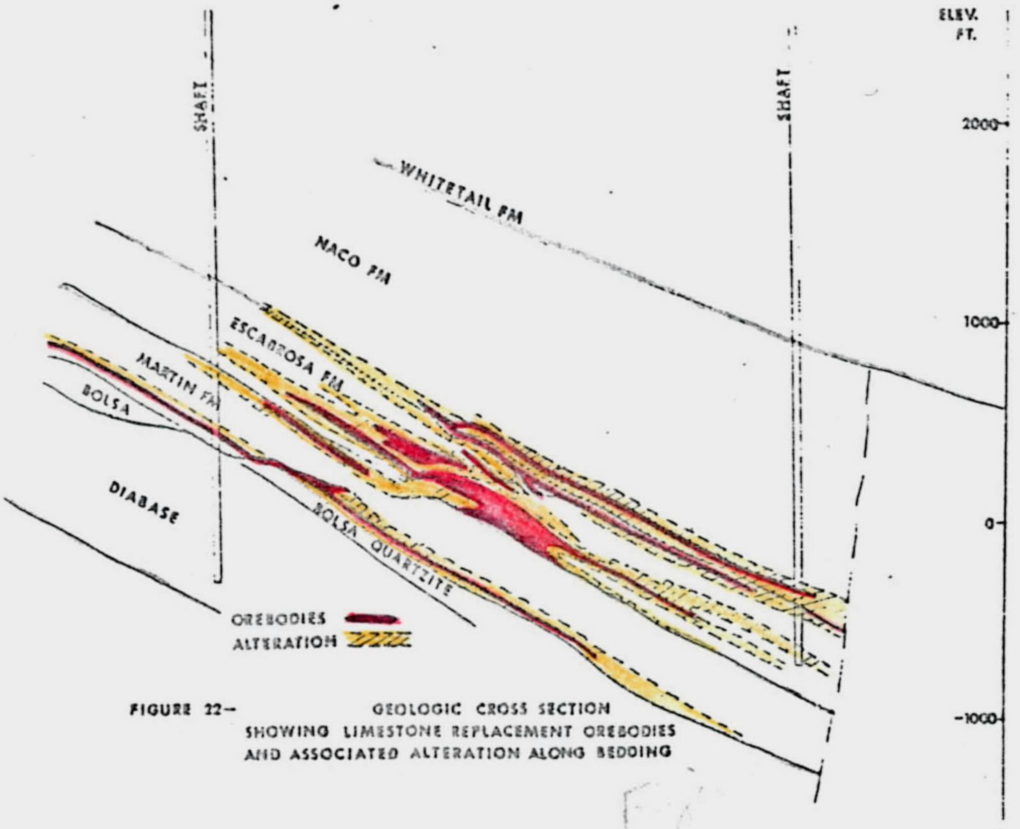

FIGURE 22— GEOLOGIC CROSS SECTION SHOWING LIMESTONE REPLACEMENT OREBODIES AND ASSOCIATED ALTERATION ALONG BEDDING

Figure 21

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September 14, 1995

Dear Jim,

Touring Ireland and the British Isles must've been a great time. I went to the Carbonate-hosted Pb-Zn Deposit meeting in St. Louis (and presented a poster) in June, but being a student, I certainly couldn't afford the fieldtrip to Ireland. I met a couple of the Irish geologists, though -- good guys! They have some great deposits and have been looking at them with a careful eye.

You're going to tour Superior in late October, eh? I'm just about to go down there myself for a tour and little presentation of some of my work to the company. I don't have a tome to send you, yet, but could probably put together a little ditty you could slip into your fieldtrip guidebook. When would you need a text by? I won't be able to work on it until about October 8, but could work on it as high priority then and have something by mid-October (?). If I may draw upon my abstracts for the Geological Society of Nevada (April 1995 Cordilleran Ore Deposits Symposium, Reno, NV) and Society of Economic Geologists (June 1995 Field conference on Carbonate-hosted Pb-Zn deposits, St. Louis, MO), I should be able to put something together in time. What do you think? I've enclosed those two abstracts with this letter which you may use as is, if you like.

As for my tome, that'll be another year in the making. I'll send you a copy when it is ready, though -- especially considering you did the original work in the district (on the replacement bodies)!

Tell me if I should write something more in October (i.e. if I have a chance at beating the deadline).

Sincerely,

Kurt

Kurt Friehauf

encl: Geol. Soc. Nev. abstract
Soc. Econ. Geol. Abstract

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Skarn and Cu-(Au)-rich massive sulfide/specularite carbonate-replacement deposits of the Superior District, AZ

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The presence of pre-mineral porphyry dikes, skarn followed by high-sulfidation, enargite-bearing Cu-Au veins and pebble breccias suggest the manto ores of the Superior district are similar to the carbonate-hosted ores of Tintic (UT), Bisbee (AZ), Yauricocha (Peru), Morococha (Peru), and Cananea (Sonora) and the carbonate-hosted analogues of high-sulfidation base metal lode veins such as at Butte (MT), Bor (Yugoslavia), Recsk (Hungary), Srednegorje (Bulgaria), Chuquicamata (Chile), Lepanto (Philippines), and Nena (Papua New Guinea).

East-dipping Paleozoic carbonates in the Superior District (26 Mt 4.7% Cu, 1 ppm Au, 45 ppm Ag, Matt Knight, Pers. Comm., 1994)) host garnet, amphibole, and talc skarn and stratabound massive specularite-copper sulfide and Pb-Zn sulfide replacement ("manto") ores where E-W-striking, enargite-bearing veins (e.g. Magma vein) intersect favorable carbonate lithologies. Favorable strata occur near the base of the Devonian Martin Formation (5 m thick "A-bed" dolostone), the lower part of the Mississippian Escabrosa Limestone (< 60 m thick dolomitic and calcitic "C-bed"), and below and above the shale at the base of the Pennsylvanian Naco Limestone (5 m thick "D-" and E-bed"). Hydrothermal fluids did not react visibly with "non-favorable" carbonate strata.

Garnet-amphibole-pyrite-(sphalerite) skarn, followed by rhythmically-layered sphalerite-magnetite-talc bodies, pre-date specularite-copper sulfide manto formation. Garnet-bearing skarn occurs predominantly as east-striking veins (i.e. the same fracture set occupied by copper ores and pre-mineral porphyry dikes) with small mantos flaring out in favorable members of the "D-bed". Amphibole-bearing skarn consists of an early, forest green, fine-grained (2-3 mm grains) variety growing on and cutting compositionally-zoned garnet grains which is in turn cut by light green coarse-grained (10-15 mm) amphibole veins. No copper minerals precipitated during skarn formation. Garnet is weakly altered to soft, tan-colored clay and locally specularite where cut by pyrite-bornite ± specularite-calcite veinlets. Skarn amphiboles have been altered to talc. Rhythmically-banded talc-magnetite skarn replaces dolomitic units and locally contains talc-altered coarse-grained amphibole veins.

Massive galena-pyrite-sphalerite-quartz mantos (< 1m thick) and replacement veins lacking associated talc alteration occur as separate bodies from the main specularite-copper-sulfide mantos. No magnetite or specularite and only traces of chalcopyrite precipitated with galena-bearing massive sulfide. Sphalerite displays chalcopyrite disease and pyrite is locally platy (a la Leadville, CO).

Massive specularite-sulfide mantos (5-60 m thick, < 90 m wide, and < 300 m down the dip) post-date skarn and consist of coarse-grained specular hematite, pyrite, chalcopyrite, bornite, minor chalcocite, and < 5% quartz. Rock types tend to be either specularite- or sulfide-dominant (>80:<20) with sharp (< 25 cm) chalcopyrite-rich contacts between types. Sulfide-dominant (2-4 mm granular pyrite-chalcopyrite (85:15) ± bornite) bodies occur as coalescing elongate pods (typically 6-25 m) within a "sea" of specularite-dominant (80-95% 1-5 mm specularite + 5-10% 2-5 mm pyrite + <10% chalcopyrite) rock that generally extends to the sharp (<10 cm wide) contact with wall-rock carbonate. Specularite-dominant rock predominates in shallower levels, along the footwall, and along the northern margin of the manto, but sulfide pods predominate at intermediate levels. WNW-elongate sulfide pods (i.e. similar orientation to veins in the district) widen at some stratigraphic levels within the specularite-dominant zone of the C-bed orebody, possibly reflecting stratigraphic control on a late sulfidizing fluid flow into favorable replacement horizons within earlier specularite. NW and NNE-striking, irregular bornite-chalcopyrite and bornite-pyrite replacement veins and bornite-matrix pyrite-bornite- + pyrite-chalcopyrite-fragment breccias are the locus of high-grade Cu-Au ore within the sulfide pods. Bornite veins commonly have rhythmically-banded bornite-pyrite or nebulous bornite-chalcopyrite/chalcopyrite-pyrite selvages. Paragenetic relations suggest an early stage of specularite + minor pyrite-chalcopyrite replacement of carbonate followed by formation of sulfide-dominant zones by sulfidation of specularite to replacement veins and masses of pyrite, chalcopyrite and bornite. Even, nearly continuous 0.1 - 0.5 cm specular hematite rinds on small (<30 cm thick) massive pyrite >> chalcopyrite mantos in limestone, suggest specularite also precipitated as a peripheral mineral zone during introduction of Cu-Fe sulfides.

Wall-rock alteration peripheral to specularite-copper sulfide mantos is characterized by mm-scale white dolomite or calcite veinlets ± specularite veinlets with bleached halos, and white talc spots (2-40 mm diam.) in dolomite within meters of the contact. Small (< 1 m) pyrite-chalcopyrite mantos do not visibly alter limestone. A 20-foot thick, quartz-eye-poor, hornblende-rich "latite" porphyry dike, where cut by massive sulfide/specularite mantos, is pervasively altered to sericite-pyrite and chlorite and cut by quartz-sericite-pyrite, specularite, and quartz-adularia ± chlorite veins. Hornblende sites were locally replaced by specularite.

Carbonate-replacement Cu-(Au) deposits associated with a high-sulfidation state Butte-type vein system, Superior District, AZ

Kurt C. Friehauf, Dept. of Geological and Environmental Sciences, Stanford University, Stanford CA 94305-2115

Copper veins in the Superior district closely resemble quartz monzonite-hosted "Main stage veins" at Butte (MT), Tintic (UT), Yauricocha (Peru), and Chuquicamata (Chile) in vein filling mineralogy and associated alteration. Carbonate-hosted ores in the Superior district are similar to the carbonate-hosted ores of Bisbee (AZ) and Yauricocha (Peru). The association of Butte, Yauricocha, Chuquicamata, and Bisbee with porphyry copper systems suggests Superior is related to an as-yet undiscovered porphyry copper system.

East-dipping Paleozoic carbonates host the stratabound massive specularite-copper sulfide and Pb-Zn sulfide replacement ("manto") ores where E-W-striking, enargite-bearing veins (e.g. Magma vein) intersect favorable carbonate strata. Favorable strata occur near the base of the Devonian Martin Formation (5 m thick "A-bed" dolostone), the lower part of the Mississippian Escabrosa Limestone (< 60 m thick dolomitic and calcitic "C-bed"), and below and above the shale at the base of the Pennsylvanian Naco Limestone (5 m thick "D-" and E-bed"). "Nonfavorable" limestone and dolostone beds that lie between the favorable horizons show little visible evidence of fluid-rock interaction more than a meter from the feeder veins.

Footwall contacts of mantos are locally discordant (on the order of a meter), but hanging wall contacts are discordant by up to tens of meters. Portions of mantos tend to be either specularite- or sulfide-dominant with sharp (< 25 cm) contacts between zones. Early replacement of carbonates by massive specular hematite with 5-15% disseminated pyrite and chalcopyrite was followed by the formation of massive pyrite-chalcopyrite ± bornite replacement veins and mantos *within* the specularite body. The time-integrated mineral association zoning is from central bornite+chalcopyrite+pyrite+quartz outward to pyrite-chalcopyrite-quartz to specularite+pyrite+chalcopyrite. Small, isolated massive galena-sphalerite-pyrite-quartz pods within limestones/dolostones occur peripheral to copper orebodies.

Wall-rock alteration adjacent to specularite-copper sulfide mantos is characterized by mm-scale white dolomite or calcite veinlets ± quartz-specularite veinlets with bleached halos within meters of the contact. At one locality, a latite porphyry dike in contact with a manto is pervasively altered to sericite-pyrite and chlorite and is cut by quartz-sericite-pyrite, specularite, and quartz-adularia ± chlorite veins. XRD analyses of siliceous sulfide breccias in the central zone of the C-bed orebody indicate the presence of dickite and zunyite -- minerals typical of hypogene advanced argillic alteration in quartzofeldspathic rocks in other Butte-type systems -- suggesting manto ores at Superior represent the carbonate-hosted analogues of advanced argillic alteration.

SEG Carbonate Conference -- St. Louis MO 1995

To:

FAX 415/725-0979

09/18/95
Transmitted
OK

Dept of Geology, Stanford Univ.

Atten: Kurt Friehauf.

Your letter & 2 abstracts arrived today.

The AGS field trip GB is scheduled to be printed by ± Oct 1. May I use your Abstracts? (yes, you said I could)(& I will).

Whats this statement (SEG Carbonate Conf) "... suggests Superior is related to an as-yet undiscovered porphyry copper systems" (1st paragraph).

Or were you just being close-mouthed since you viewed a copy of a paper prior to being published! See AZ Geol. Soc. Digest Volume 20, 1995 (came out a month or so ago).

Thanks — will see you when you are this way — give me a call.

J. D. Sell
FAX 520/578-7196

I'm not sure that last try worked.

To: James D. Sell
fax (520) 578-7196

September 19, 1995

Jim,

Yeah, I'd be thrilled if you'd include those abstracts in your field guide, especially if you include your paper on Superior East in the same volume. If AZ Digest Volume 20 is the proceedings volume from the symposium last year, I still haven't received it yet. Some printing error I hear. Your Superior East paper will certainly be referenced all of my future writings, even if I have to cite it as "in press."

You are correct about why I didn't explicitly reference the ASARCO Superior East porphyry (a combination of space limitations in the abstract and closed-mouth-itis). I agree with your wanting to connect Superior with Superior East, even though some might argue that the distance between them is a bit far (a little further than I like my standard *"Disseminated"* porphyry coppers to reach, but quite reasonable for *"Cordilleran Lode-type"* porphyry coppers [terminology of Einaudi 1982 in Titley Advances in the Geology of Porphyry Coppers volume]). I made map of the Butte district (lifted it directly out of the Graton-Sales volume) and scaled it to the same scale as my district-scale maps of the Superior/Superior East district (to act as an overlay). The similarity is striking! By coincidence, the vein orientations are the same in both districts, and there appears to be a major normal fault in both districts at the same location (Continental Fault of Butte = inferred Devil's Canyon Fault of Superior/Superior East). The Superior district corresponds spatial to the zone of Butte-type veins (Anaconda and Blue systems) at Butte and the Superior East porphyry corresponds precisely with the Continental pit disseminated porphyry copper deposit of Butte. The distances involved are certainly not an issue! Your observations that the Superior East porphyry is dominated by dikes and sheeted chalcopyrite-poor veins (i.e. high sulfidation state copper mineral assemblages) supports the Cordilleran Lode-type porphyry model (dominated by a strong structural control on magma emplacement and vein formation). My work has brought to light some other evidence supporting the link, but I still need to get permission to disseminate that publicly. I definitely think you are right on in linking Superior and Superior East.

I may be able to put together one more little piece to put in the fieldguide before October 1, but don't wait up for me. I need to pass it by Magma first.

Kurt

Kurt Friehauf
fax (415) 725-0979

Kurt Friehauf
Dept. of Geological and Environ. Sciences
STANFORD UNIVERSITY
STANFORD, CALIFORNIA 94305

TO: James D. Sell
2762 W. Holladay St.
Tucson AZ 85746-3055

Kurt Friehauf
APP EARTH SCIENCES
Fax: 415/ 725-0979

09-22-95

Dear Kurt:

Your fax of Sept. 19 arrived in memory OK and after some problem (needed to change out the printer cartridge) I was able to recover it and print it out.

Thanks for the Butte-Superior comparison, however it still opens up some additional questions that only deep drilling will answer. I see in Pay Dirt that Magma has released more $$ for drilling at Superior, perhaps they will stumble into some answers.

Thanks again and hope to see another note in time for the GB.

Jim

Jim Sell
Fax 520-578-7196

FIG. 6. *Relationship between Ore and Diabase Wall Rock in the Magma Vein, projected to a vertical, east-trending section (after Gustafson, 14). Stoped areas indicate areas of ore, and specific patterns indicate where either both walls, one wall, or neither wall is diabase. These relationships show that diabase had no appreciable effect on the distribution of ore in the vein.*

can best be observed. Evidence for localization of ore shoots in the Central part of the Magma vein by premineral transverse structure is abundant. Major crossfaults, many of which have undergone postmineral movement, frequently serve as bounding structures controlling the lateral extent of individual ore shoots. Lesser cross structures appear to have imposed an added permeability upon portions of the vein-fault that are the locus of ore shoots. By inference then, this evidence may be extrapolated to the Main ore body, where much of the evidence for control by transverse structure has been obliterated.

Complex vein splits and branch veins are a structural characteristic of the zone of Central ore bodies above the 4400 level. Increased permeability of this portion of the vein, imposed through splits and branches, appears to be a major factor in localization of mineralization.

These factors suggest that the principal condition that determined specific location of mineral deposition in the Magma vein-fault is permeability imposed by structure. Shearing across irregularities in strike and dip of the vein-fault created some of the permeable zones. The fractures associated with some of the transverse structures created additional permeable zones, but other transverse structures imposed restrictive barriers to the lateral migration of ore fluids along the vein. The net effect of the permeable zones was to provide channelways along which the flow of ore fluids could concentrate.

LIMESTONE-REPLACEMENT DEPOSIT The favorability of the lower part of the Martin Limestone for replacement mineralization has been observed in many mines and prospects throughout southern Arizona. To a lesser extent, specific favorability for replacement has also been shown by the lower and the upper beds of the Escabrosa Limestone in the Superior area. It is not yet known why these beds are particularly subject to replacement, but they obviously were accessible to the ore fluids and susceptible to chemical attack during hydrothermal activity.

Figure 7 shows a north-south section

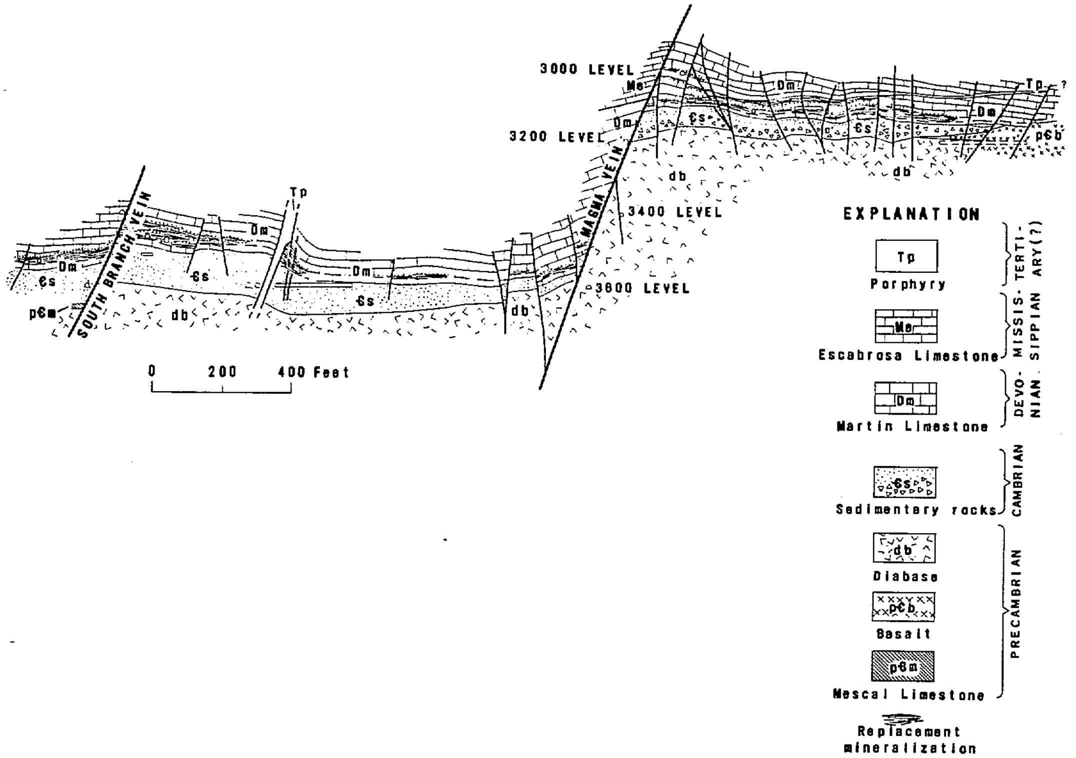

FIG. 7. *Vertical North-Trending Section through the Limestone-Replacement Deposit, Magma Mine (looking west). Some ore shoots show direct connection with veins, but others are isolated. (See Figure 5 for location of section).*

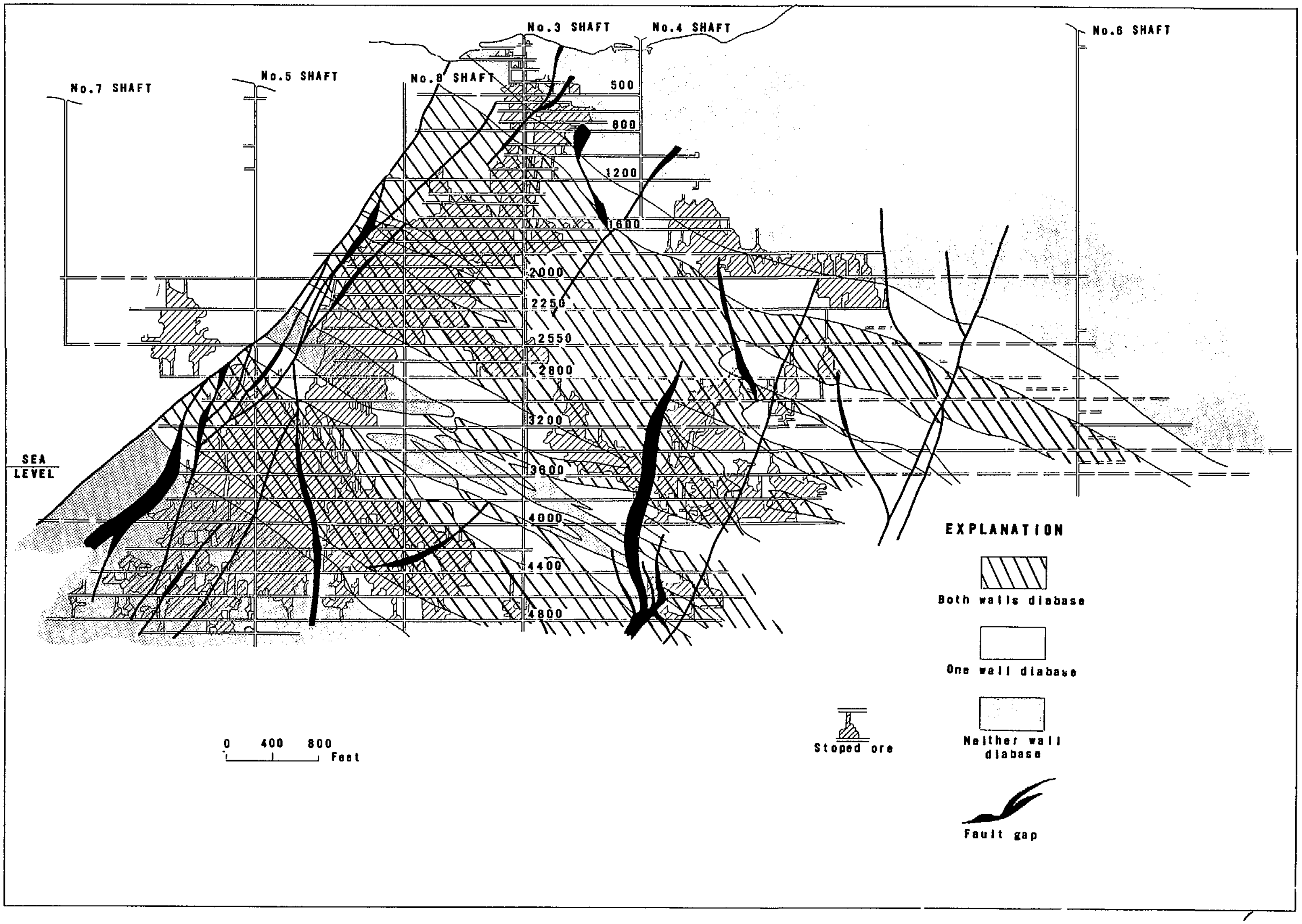

FIG. 6. *Relationship between Ore and Diabase Wall Rock in the Magma Vein, projected to a vertical, east-trending section (after Gustafson, 14). Stoped areas indicate areas of ore, and specific patterns indicate where either both walls, one wall, or neither wall is diabase. These relationships show that diabase had no appreciable effect on the distribution of ore in the vein.*

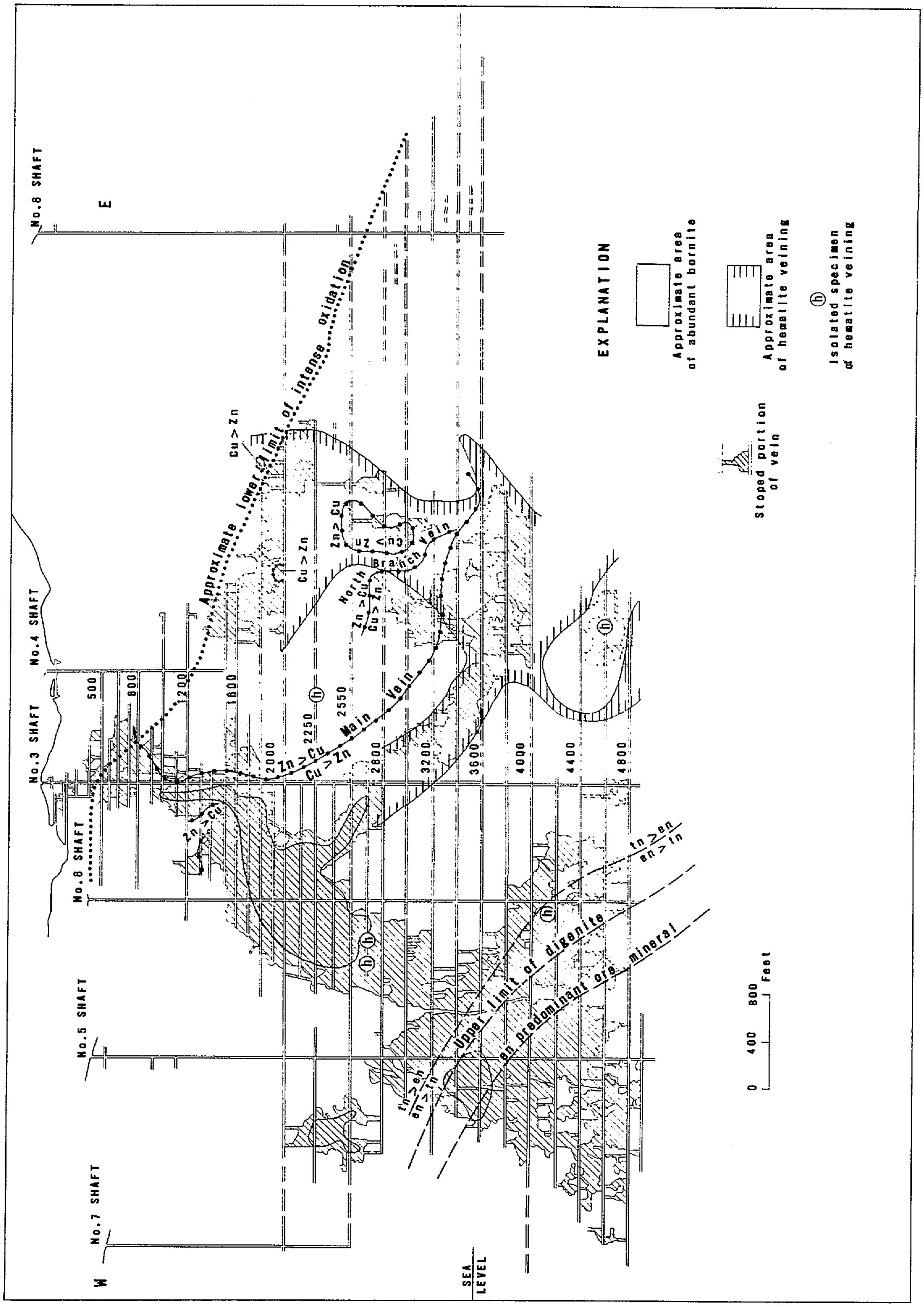

FIG. 5. *Pattern of Mineral Zoning in the Magma Vein, projected to a vertical, east-trending section.*

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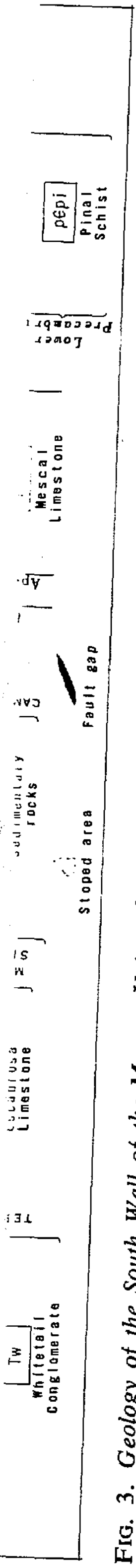

FIG. 3. *Geology of the South Wall of the Magma Vein. The Geology has been projected to a vertical, east-trending plane. Stoped areas, junctions of important branch veins, and axis of change of dip of the vein are indicated.*

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side of the Main fault. The Main ore body has been stoped continuously from near surface to the 4900 level. The "West ore body" is a smaller offset portion of the Magma vein that was mined on the west side of the Main fault between the 2000 and 2800 levels. The "Central ore bodies" make up a zone of discontinuous ore shoots east of No. 3 shaft that, in gross outline, plunge steeply westward roughly parallel to the rake of the Main ore body. The Central ore bodies have been mined discontinuously from the 1600 level to the 4800 level.

The Magma vein occupies an east-striking fault zone that has been opened for more than 10,000 feet along the strike. From the surface outcrop down to a westward-raking "axis of reversal of dip" (Figure 4), the vein dips about 65°N. Below this axis, the dip reverses and continues downward to the deepest (4900) level with an average south dip of about 78°. Direction and amount of net slip along the Magma fault zone has not been determined, owing to the difficulty of matching identical points on the opposite sides of the zone. The best match of geology on the north and south walls of the vein suggests that the net movement is normal (south side down) and is predominantly down the present dip, with only a small component of right-lateral slip. A rotational movement is evident, as the vertical displacement increases from 350 feet near the Main fault to 450 feet toward the east end of the mine.

The structural map (Figure 4) of the 2550 level is a representative example of horizontal section through the vein and also shows branches of the vein and important offsets. Three principal sets of fractures have been recognized in the mine:

(1) The earliest consists of the east-striking Magma vein fault and a persistent set of lesser shears that branch away at small angles toward the northwest and southeast. This is the set of fractures that has been most extensively mineralized.

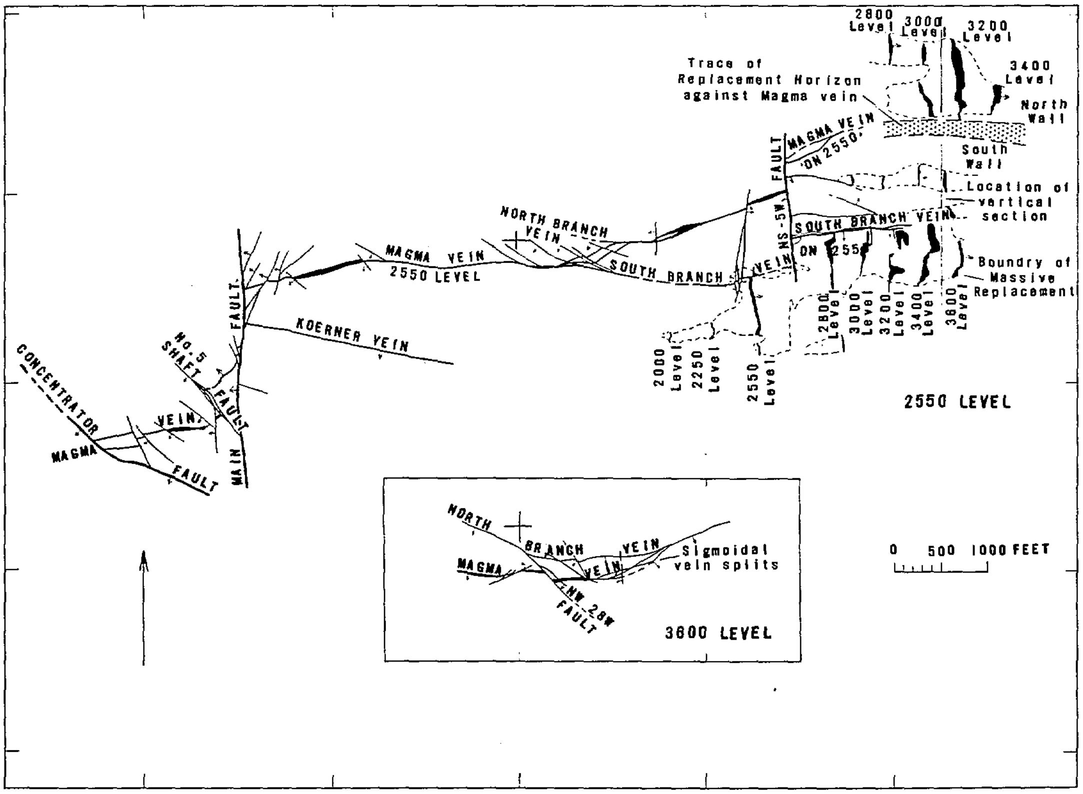

FIG. 4. *Structural Map of the 2550 Level of the Magma Mine. The map shows the Magma vein, its major branches, significant subsidiary fractures, offsets by major faults of the north-striking set, and the Koerner vein. The outline of the east-dipping limestone-replacement ore bodies is projected to the diagram. The inset shows a structural map of part of the 3600 level of the mine.*

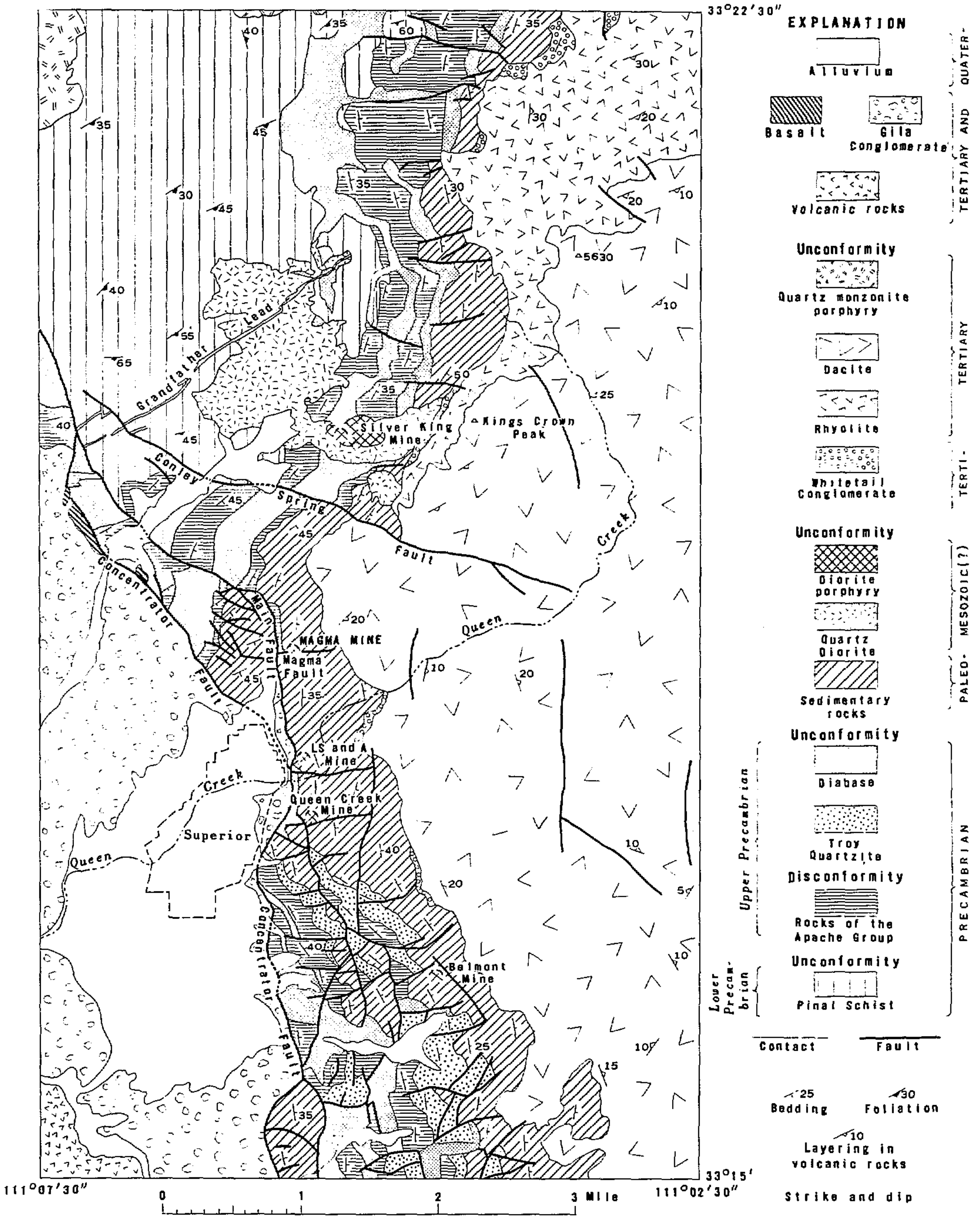

FIG. 2. *Geologic Map of the Vicinity of the Magma Mine (from D. W. Peterson, 17).*

PENNSYLVANIAN

Naco Limestone. Medium- to thin-bedded, light-gray to white to very pale blue limestone, contains local chert nodules and thin interbeds of calcareous shale; red shale at base. Fusulinids, brachiopods, corals, bryozoa locally common. Thickness, 0 to 1400 feet.

MISSISSIPPIAN

Escabrosa Limestone. Very light gray to dark-gray limestone. Upper part medium-

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Lower part thi
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Martin Limestor
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DISCONFORMITY

Sedimentary ro
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UNCONFORMITY

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Basalt. Lava
of dusky
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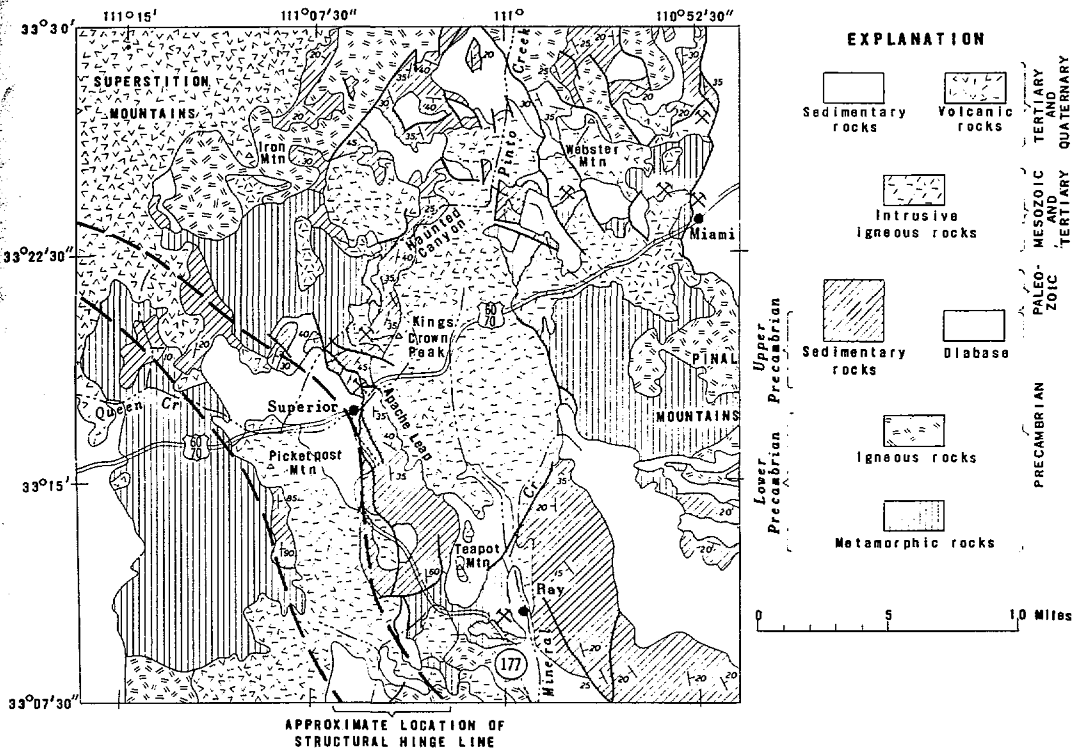

FIG. 1. *Geologic Map of the Region around the Magma Mine. Geology has been generalized, with modification, from the following maps and reports: F. L. Ransome* (*5*), *N. P. Peterson,* (*18*), *E. D. Wilson, et al.* (*11, 12*), *and D. W. Peterson* (*13, 17*).

STRATIGRAPHIC COLUMN

QUATERNARY AND TERTIARY

Basalt. Small, irregular intrusive bodies of gray, aphanitic basalt, chiefly plagioclase and pyroxene, some olivine. Generally dense, locally vesicular.

Gila Conglomerate. Fluvial deposits of pebble- to boulder-sized, angular to subrounded fragments of all older rocks in coarse-grained, poorly sorted, arkosic sandstone matrix.

Volcanic rocks. Lava flows of rhyolite that grades to perlite and pumice, and beds of tuff.

UNCONFORMITY

TERTIARY

Quartz monzonite porphyry. Small stocks; light-colored phenocrysts of quartz, K-feldspar, and plagioclase in very fine-grained groundmass.

Dacite. Zoned ash-flow sheet, includes welded and nonwelded tuff. Phenocrysts of plagioclase, quartz, biotite, and sanidine in lithoidal to glassy groundmass. Thickness, 500 to 2000 feet.

Rhyolite. Lava flows of rhyolite, grades to perlitic obsidian and devitrified pale-yellow felsite; minor deposits of tuff and tuff breccia. Thickness, 0 to 2000 feet.

TERTIARY(?)

Whitetail Conglomerate. Fluvial deposits of angular to subangular fragments derived from older rocks, mainly from underlying or nearby rocks. Thickness, 0 to +600 feet.

UNCONFORMITY

MESOZOIC

Diorite porphyry. Hypabyssal intrusive rock, elliptical body at Silver King, thin dikes and sills elsewhere. Plagioclase and locally hornblende in aphanitic groundmass; partially to completely altered to clay, sericite, and calcite.

Quartz diorite. Small stock; medium- to fine-grained rock composed of plagioclase and variable amounts of hornblende, pyroxene, biotite, and sporadic quartz.

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MINING ENGINEERS
of
AIME

540 ARAPEEN DRIVE · SALT LAKE CITY, UTAH 84108

PREPRINT
NUMBER

78-I-19

QUANTITATIVE MEASUREMENT OF WALLROCK ALTERATION IN THE EXPLORATION OF BURIED MINERAL DEPOSITS

D. M. Hausen
Chief Mineralogist

Newmont Exploration Limited
Danbury, Connecticut

For presentation at the 1978 AIME Annual Meeting
Denver, Colorado - February 28 - March 2, 1978

San Manuel-Kalamazoo

Abstract. A quantitative x-ray diffraction method has been developed for the analysis of alteration minerals in wallrock. Alteration data are plotted and contoured (analogous to geochemical data). Alteration trends outlined by this technique correlate closely with geochemical anomalies, and in some cases extend well beyond the perimeter of anomalous base metal values.

"Monomineralic contouring," applied originally to porphyry-type mineralization, has been extended to other types of mineralization, including volcanogenic massive sulfide deposits. Equipment and techniques used in the quantitative measurement of alteration mineralogy are discussed.

Introduction

For many years, exploration geologists have recognized concentric zones of altered rock around sulfide deposits, and have attempted to correlate in various ways their association with ore bodies. Newmont has successfully developed a quantitative method for the measurement of alteration intensity (and zoning) by means of x-ray diffraction analysis of alteration minerals. This XRD method is relatively simple in concept, and has been applied in a practical sense to the evaluation of alteration trends in a variety of porphyry and massive sulfide deposits.

Conceptual Development of the Method

Various attempts have been made by geologists to interpret and classify alteration zoning in porphyry copper deposits, based on metamorphic facies, stages or metasomatic changes, resulting in the use of such terms as propylitic, argillic, phyllic, potassium silicate, pneumatolytic, magmatic, epithermal, mesothermal, hypothermal, etc., to describe zoning. Many of these terms are qualitative, overlapping, academic and often ambiguous in usage, requiring time-consuming interpretive microscopic study. Petrographers, often as not, may disagree on the classification of types of alteration. Geologists may argue on the exact terminology and the relative significance of different types of alteration, but are generally in agreement on the importance of alteration trends in defining favorable mineralized zones, belts or districts. For these reasons, wallrock alteration, as an exploration guide, merits more quantitative study in the evaluation of mineralized prospects.

Newmont has developed new methods for the quantitative measurement of alteration halos, including such techniques as (a) whole rock sampling(1), (b) quantitative XRD analysis of alteration minerals(2), (c) computer processing of XRD alteration data(3,4), and (d) plotting and monomineralic contouring of alteration data(2,4). Thousands of whole rock samples from gridded surface exposures and intervals of drill core have been analyzed in the past two years for eight or more mineral components per sample, converted into mineral percentages by computer processing, plotted and contoured to provide alteration trends.

This technique has been applied successfully to a number of mineralized prospects, including several known economic deposits, where the intensity of alteration has been measured vectorially around centers of mineralization. The resulting alteration plots are contoured to delineate trends in porphyry type mineralization, to outline probable limits of mineralization, and to indicate optimum vector directions for highest anticipated grade of mineralization.

As a result of this work, other groups have become interested in developing the method. Dr. D. Ayres of the CSIRO, N.S.W., Australia, has applied essentially the same techniques discussed in our earlier paper(5,6) to the study of the Mt. Fubilan deposit in New Guinea and also to the Moonmera deposit in Queensland. They have apparently been successful in using a computer program (KWIK R8) for direct intensities and ratios to indicate areas of high and low abundance of each mineral, but no attempt was made to determine percentages. Dr. J. Franklin, professor at Lakehead University, Thunderbay, Canada, was also successful in applying quantitative XRD techniques to the study of the volcanogenic Mattabi massive sulfide deposit(7). However, his quantitative XRD work was devoted mostly to the carbonate minerals, dolomite, calcite, siderite, etc.

The quantitative measurement of alteration is a relatively new concept to economic geologists and is based on the analysis of alteration minerals in representative samples of altered wallrock, and the plotting and contouring of alteration data. Techniques of x-ray diffraction analysis of alteration minerals and monomineralic contouring of alteration data have been pioneered to assist the exploration geologist in the evaluation of mineralized prospects.

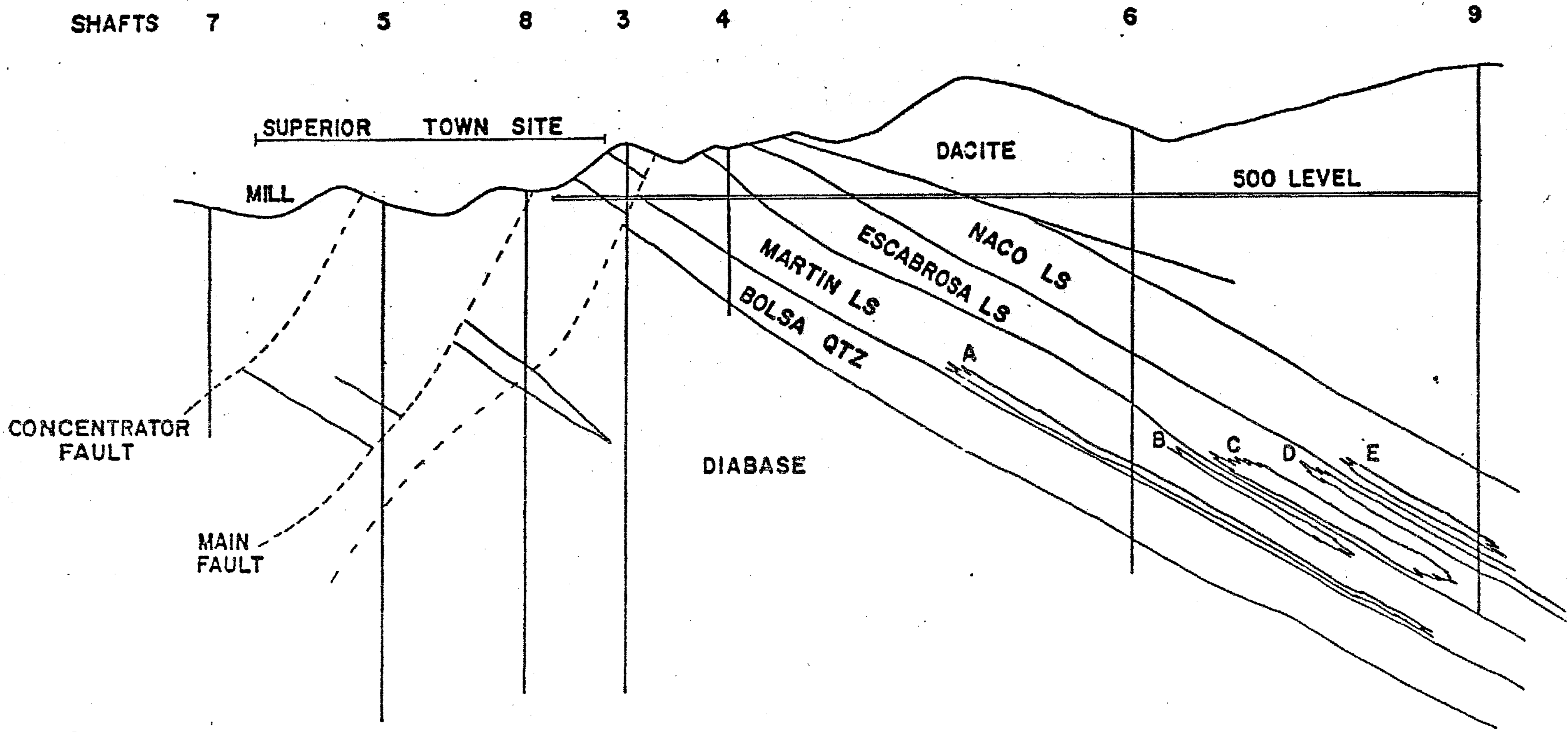
Future objectives are to sample and evaluate new deposits for the purpose of (a) determining favorable trends and drilling targets for exploration and development drilling, (b) comparing alteration patterns for various types of mineralization to determine the most favorable alteration parameters for different types of deposits, and (c) estimating optimum vector directions toward economic mineralization, and maximum distances that such mineralization can be recognized in whole rock sampling.

Techniques of Quantitative Evaluation

Various methods have been developed and described by numerous investigators for the evaluation of wallrock alteration, notably including, (a) megascopic changes that are visually distinguishable in field mapping, (b) microscopic features detectable by means of a petrographic microscope, and (c) geochemical and/or mineralogic variations that are measurable by means of quantitative analysis. The latter method has been developed and applied extensively by geochemists in the evaluation of various elements, notably pathfinder metals. However, the use of mineralogic data has been limited by the inherent lack of precision of most instruments designed for the analysis of solid crystalline phases, including the x-ray diffractometer. This limitation has been largely overcome in recent years (1,2,3,4) by the use of special techniques, equipment and accessories in the preparation and analysis of finely pulverized samples by x-ray diffraction.

Over the years that x-ray diffraction has been

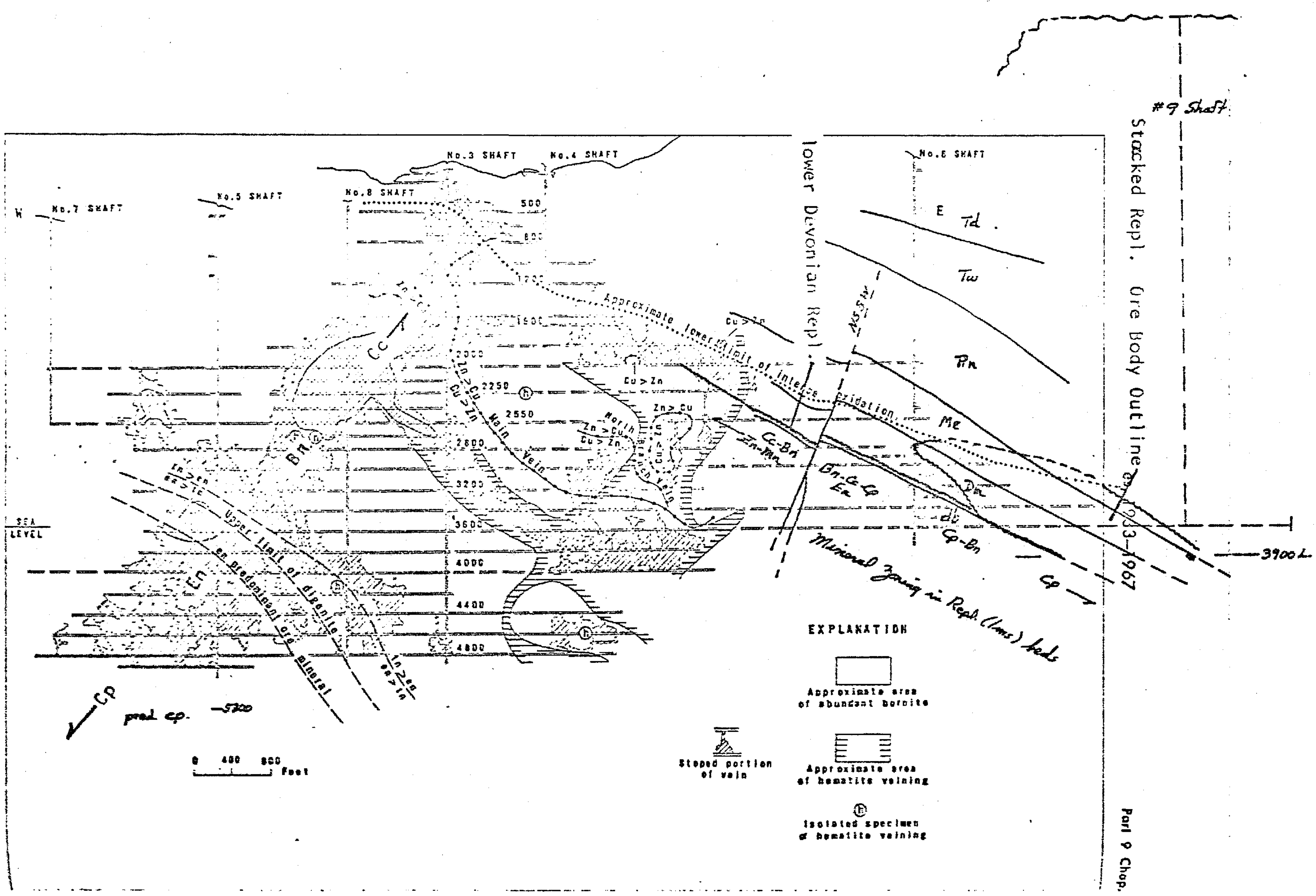
Figure



From: AGS FT#1, 1981

GENERALIZED VERTICAL
EAST WEST SECTION

MAGMA COPPER CO.
SUPERIOR, ARIZ.
E 1000'

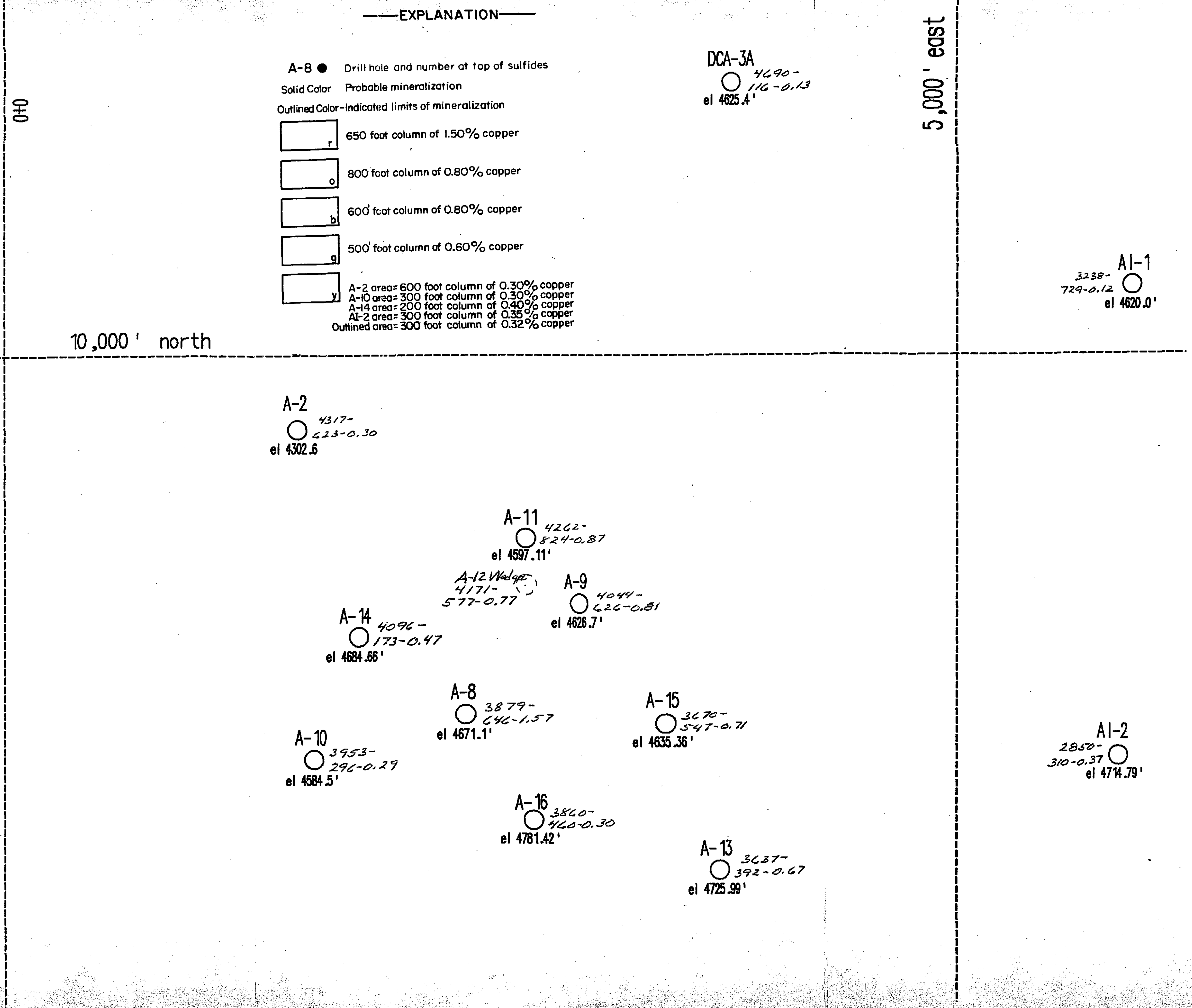


Modified from Hammer (Graton-Sales Vol., AIME)

Part 9 Chap. 61

Fig. . Pattern of Mineral Zoning in the Magma Vein.

Intercept Depth	Thickness	%Cu
4317 -	623	- 0.30



NORTH

ASARCO Incorporated

SUPERIOR EAST PROJECT
DRILL HOLE SURVEY
PINAL COUNTY, ARIZONA

1"=500'
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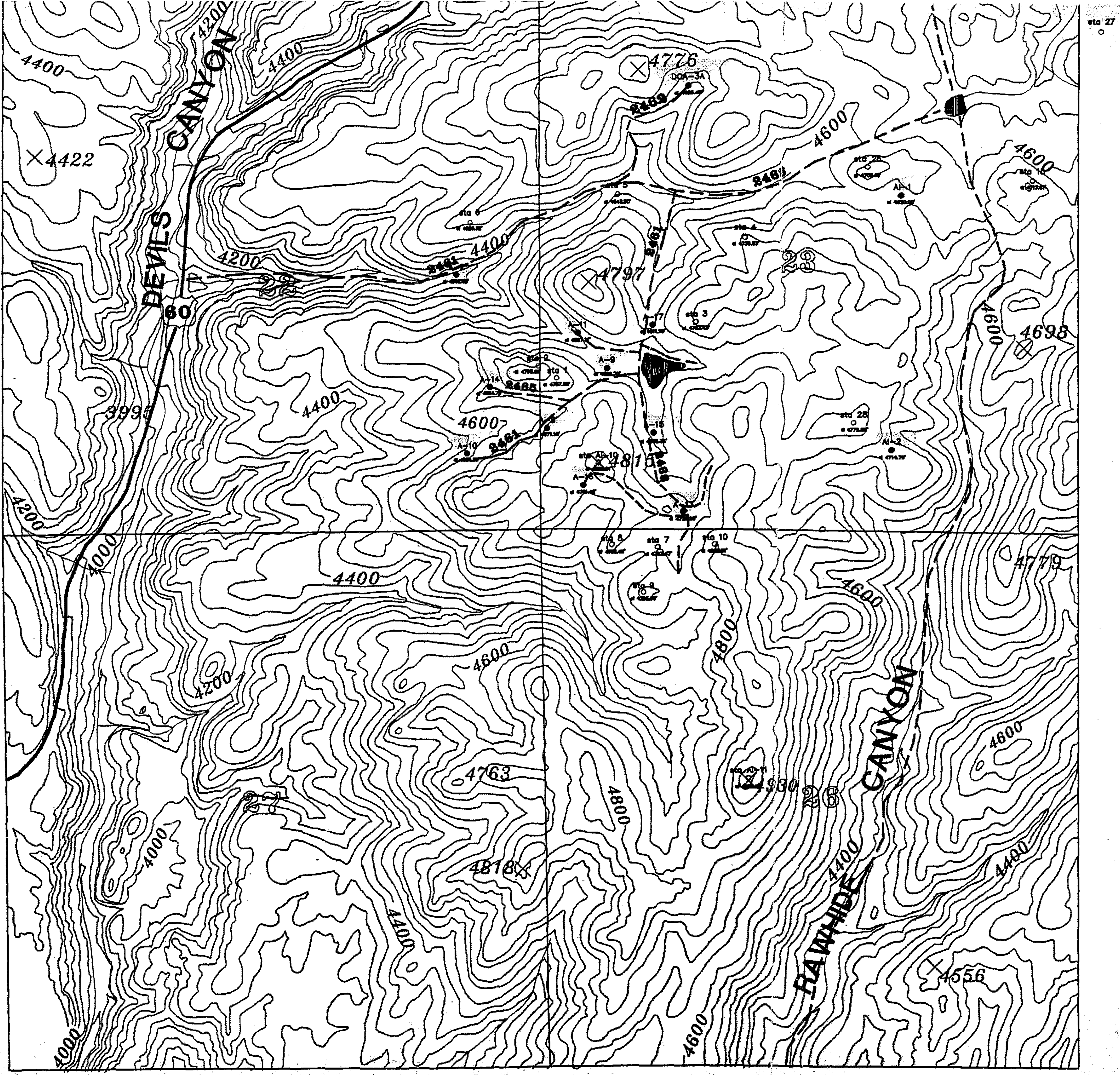

ASARCO

ASARCO SOUTHWESTERN EXPLORATION

SUPERIOR EAST PROJECT
DRILL HOLE - STATION MAP

PINAL COUNTY, ARIZONA

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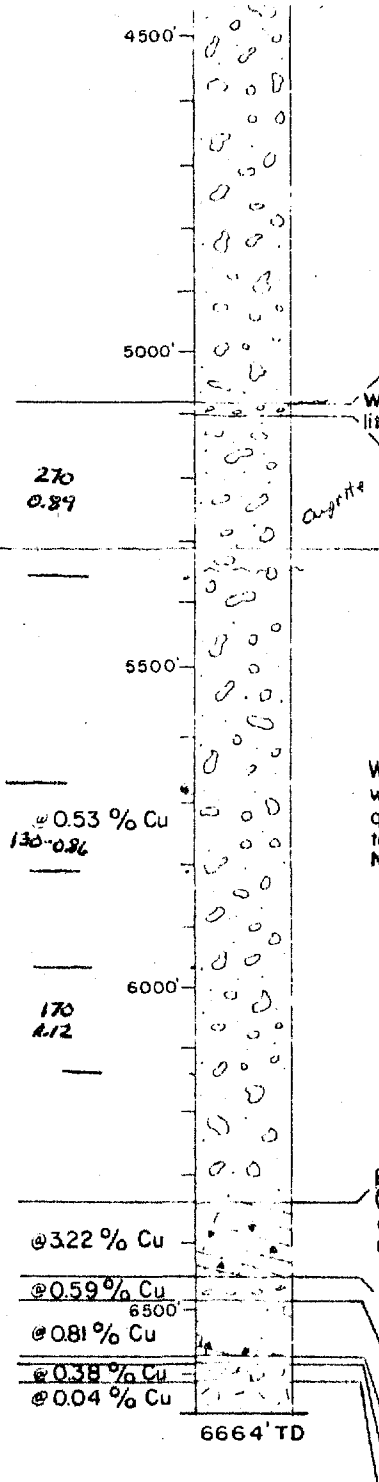


Cuprite 5083-5850

5083'
Whitetail Conglomerate,
lithic tuff. Strong cuprite.
5102'

Whitetail Conglomerate
with clasts of sch, db,
qtzite, qm & lms. Sparce
to strong amounts of
Native Copper & cuprite

NOTE:

5080-6540 = 1460 ft. @ 0.76 % Cu
5680-6540 = 860 ft. @ 0.98 % Cu

6339'
Escabrosa Limestone
(Mississippian) Brecciated lms. Flat fault zone
6386-6396. Sparce to
very strong Native Copper, cuprite & chrysocolla
6448'
Whitetail Conglomerate
with clasts of lms, qm &
db moderate Native Copper
6484'
Escabrosa Limestone.
Replaced by hematite &
brecciated Native Copper
6571'
Fault Zone. Cemented
fault gouge with chalcocite
& sheared qm
6581'
Pinal Schist intruded by
biotite qtz monzonite.
Sparce to strong py, cpy & mo
6610'
Biotite qtz. monzonite with
traces of py, cpy & mo.

T 1 S, R 13 E

SW 1/4 SW 1/4 SW 1/4 Sec. 27

GRAPHIC LOG & ASSAY RESULTS
of
DRILL HOLE A-4
SUPERIOR EAST PROJECT

GILA & PINAL COUNTIES, ARIZONA

SCALE: 1" = 300'

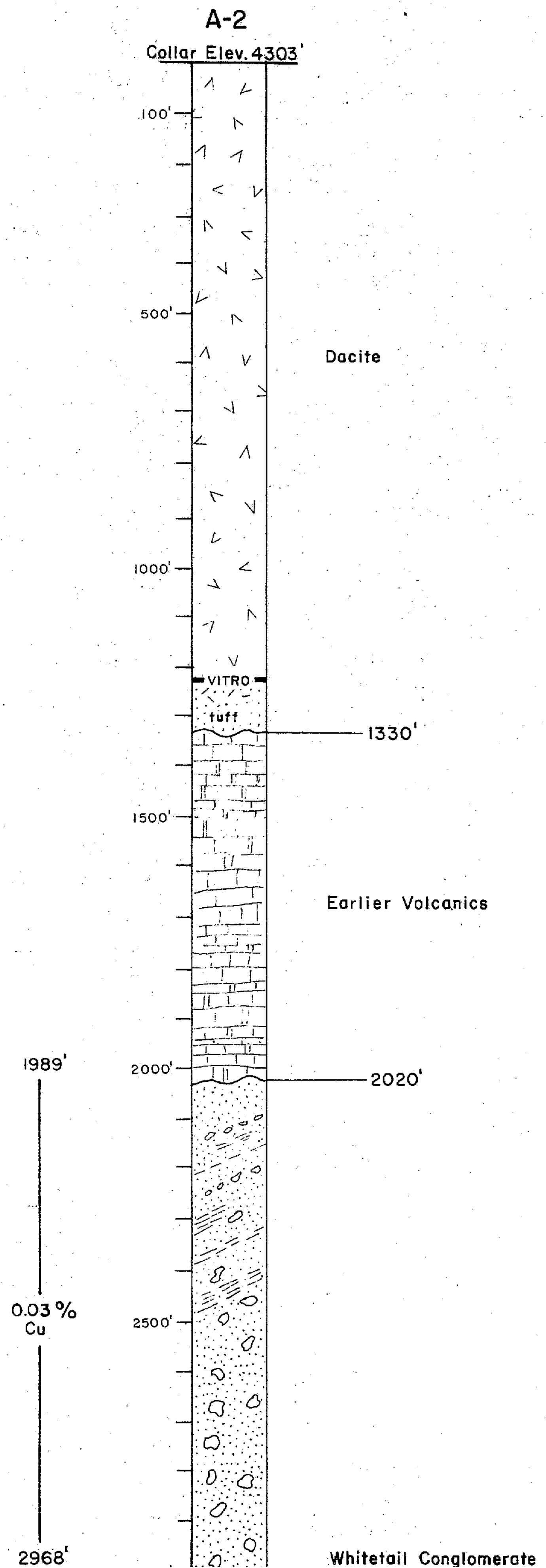
R.B.C. Dec. 2, 1971

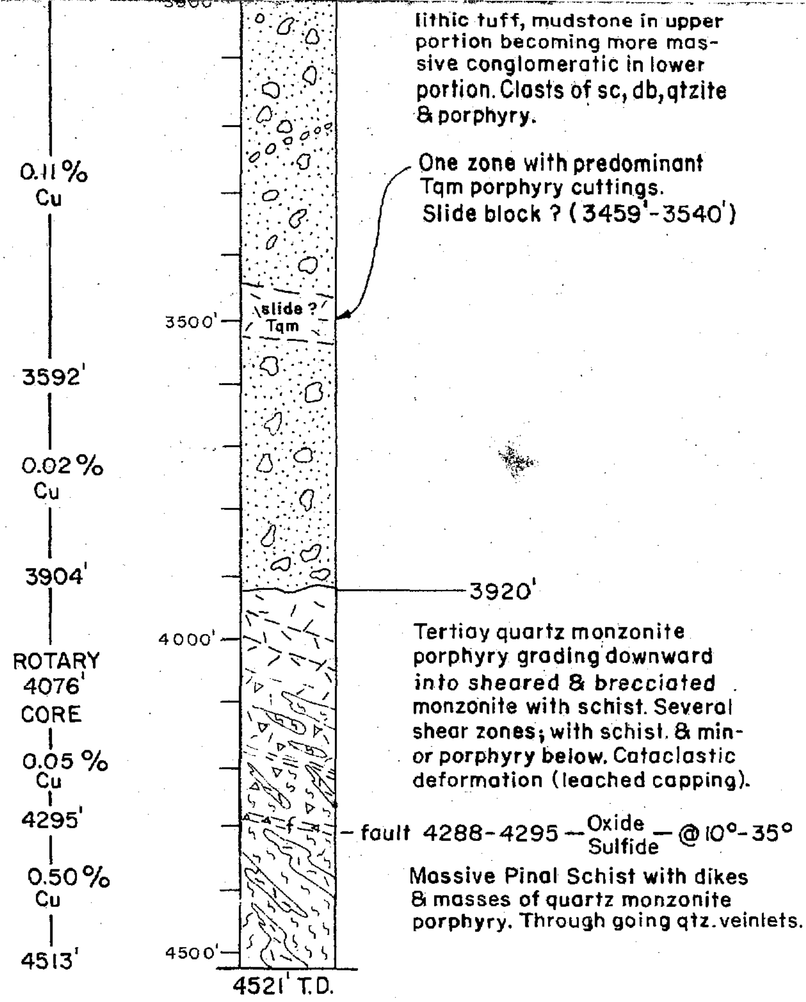
2486-B

ASARCO DRILL HOLE A-2

Rotary: Surface-4076 feet
with spot cores at 2559-2574
3540-3550
4075-4076
Mayhew 3000, air drilled
January 13-February 7, 1972
8¾"-6¼" hole.

Core: 4076-4521 feet
Longyear TRK-44
NX Coring
March 4-18, 1972





lithic tuff, mudstone in upper portion becoming more massive conglomeratic in lower portion. Clasts of sc, db, qtzite & porphyry.

One zone with predominant Tqm porphyry cuttings. Slide block ? (3459'-3540')

Tertiay quartz monzonite porphyry grading downward into sheared & brecciated monzonite with schist. Several shear zones; with schist. & minor porphyry below. Cataclastic deformation (leached capping).

– fault 4288-4295 – Oxide / Sulfide – @ 10°-35°

Massive Pinal Schist with dikes & masses of quartz monzonite porphyry. Through going qtz. veinlets.

NOTE: Hole lost w/corebarrel & rods in bottom. See Hole A-2 W (map # 2486-F) for wedged hole.

Individual assays for the hole are found in Assay Report, dated March 24, 1972.

T1S, R13E.

NW 1/4 NE 1/4 SE 1/4 of Sec. 22

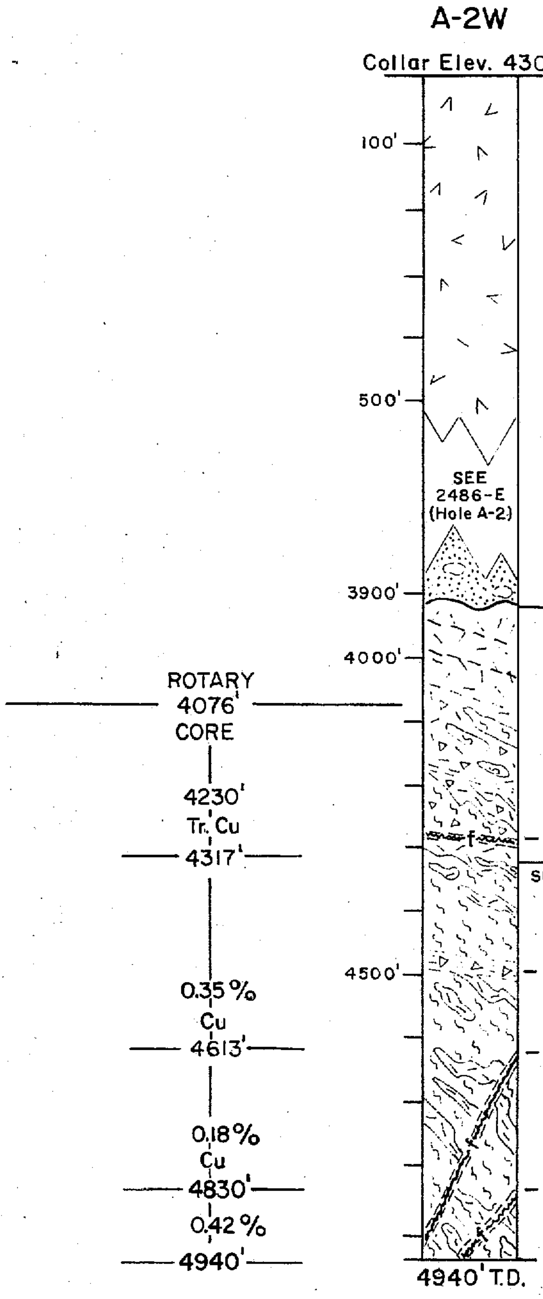
GRAPHIC LOG & ASSAY RESULTS
of
DRILL HOLE A-2
SUPERIOR EAST PROJECT

GILA & PINAL COUNTIES, ARIZONA

SCALE 1" = 300'

J.D.S. July 8, 1972

2486-E



Dacite

Whitetail Conglomerate

3920'

Tertiary Quartz Monzonite porphyry grading downward into sheared and brecciated porphyry with schist inclusions. Decreasing schist to fault. Cataclastic deformation (leached capping).

– fault 4276'-4289' – @ 10°-35°

4317' base of Oxidation

Pinal Schist with dikes and masses of porphyry; numerous shears, gouge, & fault zones. Through going qtz veinlets

– shear zone 4486'-4512' @ ± 30°

As above, end of chalcocite films @ 4530'

– fault 4613-4622 – @ 70°-80°

Pinal with very minor porphyry, broken, through going qtz veinlets.

– fault 4830-4834 – @ 45°-60°

Pinal with some dikes & masses of qtz monzonite, sheared, general crushed appearance, increased sulfides & specularite.

ASARCO DRILL HOLE A-2W (Wedge)

Hole wedged from previous Hole A-2.
See map no. 2486-E for units above 3920 feet.

Wedge at 4230 feet.

CORE: 4230-4940 feet
Longyear TRK-44
NX Coring
April 19-May 17, 1972

NOTE: Individual assays for the hole is found in Assay Report, dated May 26, 1972.

T 1 S, R 13 E.
NW 1/4 NE 1/4 SE 1/4 of Sec. 22

GRAPHIC LOG & ASSAY RESULTS of DRILL HOLE A-2W

SUPERIOR EAST PROJECT

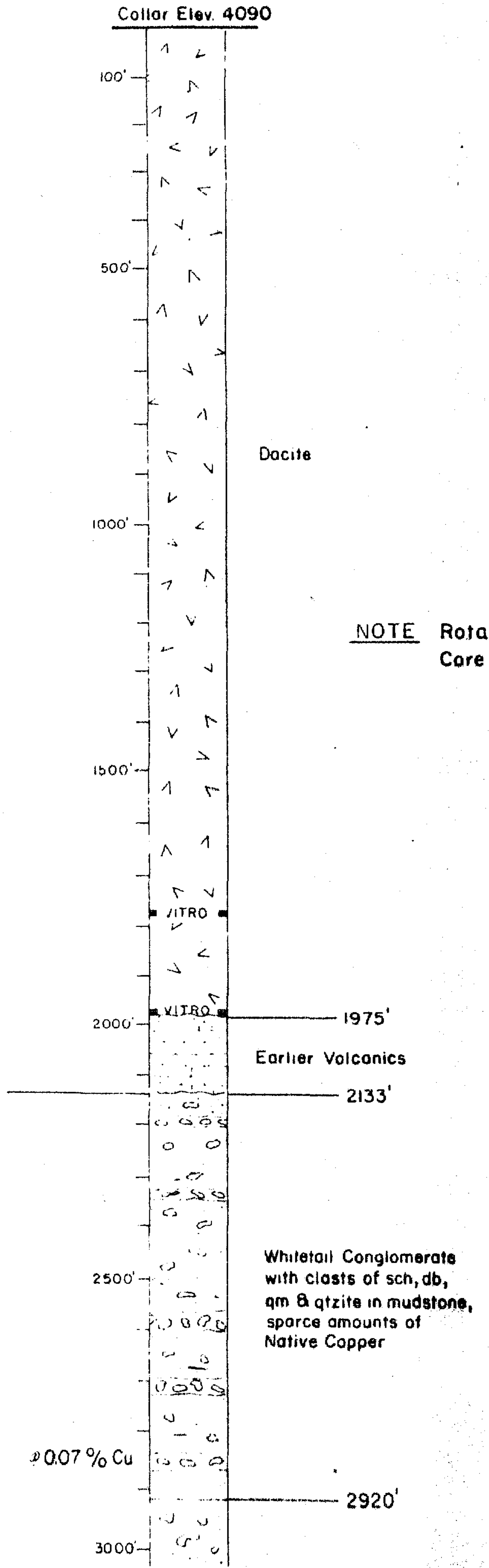
GILA & PINAL COUNTIES, ARIZONA

SCALE 1" = 300'

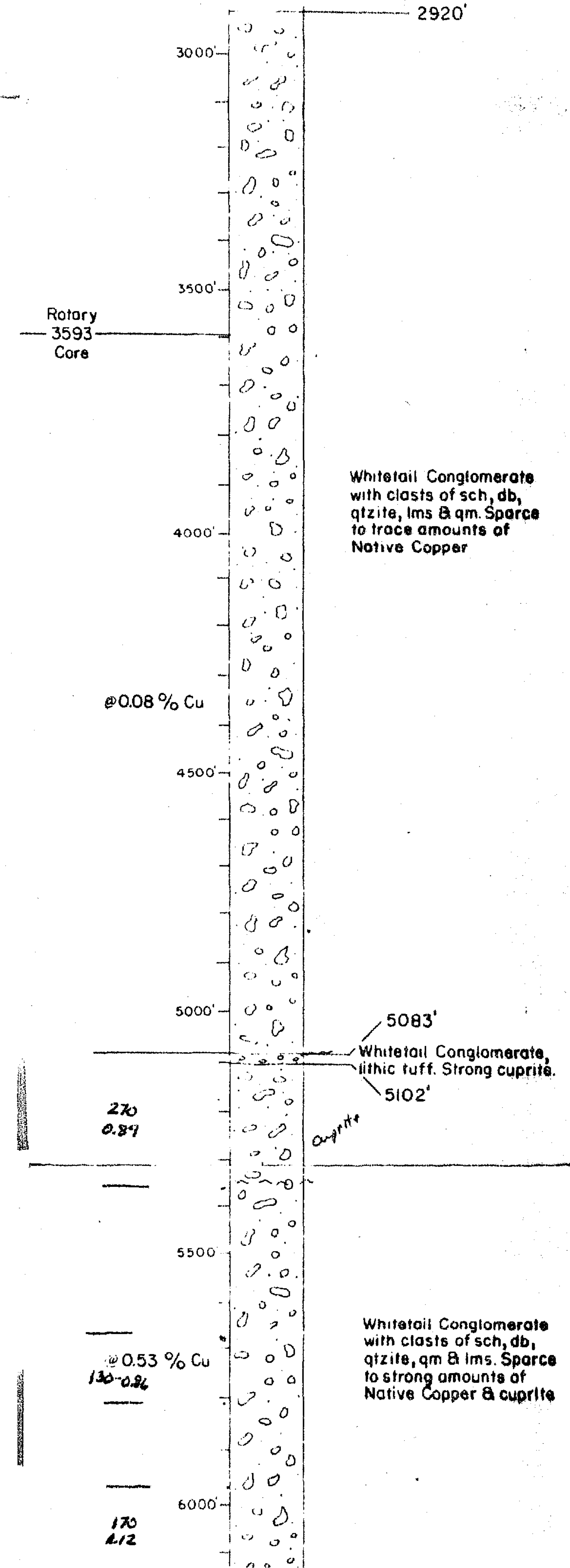
J.D.S.

July 8, 1972

A-4



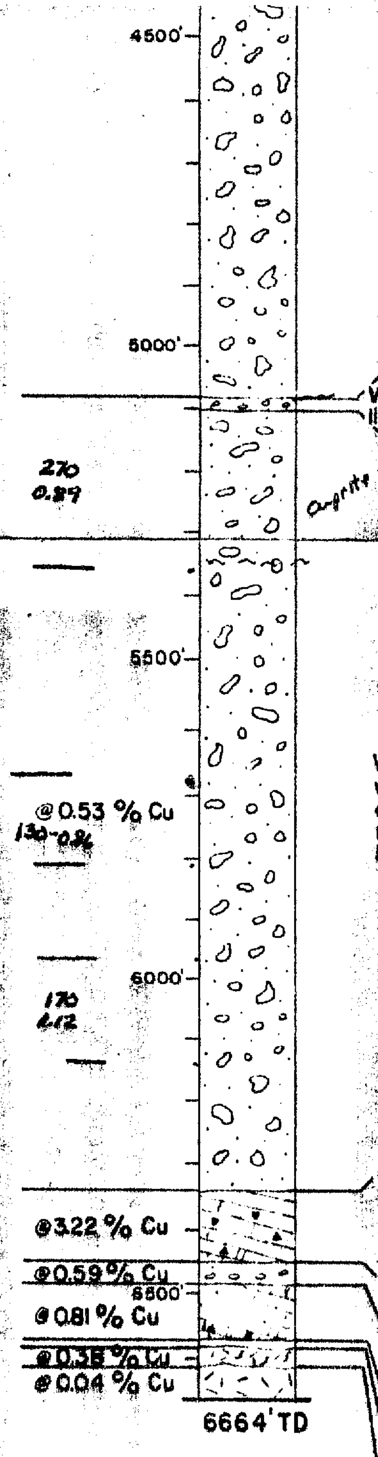
NOTE Rotary : Surface - 3593' (May 1 - July 21, 1971)
Core : 3593' - 6664' (August 17 - November 4, 1971)



Cuprite 5083- 5350

NOTE:

5080-6540=1460 ft. @ 0.76 % Cu
5680-6540= 860 ft. @ 0.98 % Cu



Cuprite 5083- [illegible]

5083'

Whitetail Conglomerate, lithic tuff. Strong cuprite

5102'

Whitetail Conglomerate with clasts of sch, db, qtzite, qm & lms. Sparce to strong amounts of Native Copper & cuprite

NOTE:
5080-6540=1460 ft @ 0.76 % Cu
5680-6540= 860 ft @ 0.98 % Cu

6339'

Escabrosa Limestone (Mississippian) Brecciated lms. Flat fault zone 6386-6396. Sparce to very strong Native Copper, cuprite & chrysocolla

6448'

Whitetail Conglomerate with clasts of lms, qm & db moderate Native Copper

6484'

Escabrosa Limestone Replaced by hematite & brecciated Native Copper

6571'

Fault Zone. Cemented fault gouge with chalcocite & sheared qm.

6581'

Pinal Schist intruded by biotite qtz monzonite. Sparce to strong py, cpy & mo.

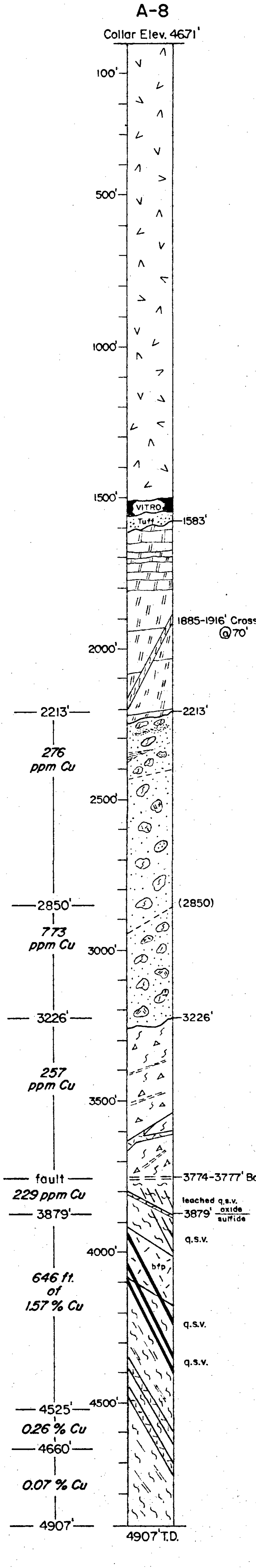
6610'

Biotite qtz. monzonite with traces of py, cpy & mo.

T 1 S, R 13 E
SW ¼ SW ¼ SW ¼ Sec. 27

GRAPHIC LOG & ASSAY RESULTS
of
DRILL HOLE A-4
SUPERIOR EAST PROJECT
GILA & PINAL COUNTIES, ARIZONA
SCALE: 1" = 500'

R.E.C. Dec. [illegible] 1971



ASARCO DRILL HOLE A-8

CORE: Surface-1971' NC
1971'-3197' NX
3197'-4907' BX

Joy Manufacturing Co.
Joy-22
Surface - 1971'
Aug. 8 - Sept. 15, 1976
Joy-22 Heavy Duty
1971'-4907' T.D.
Sept. 16 - Dec. 29, 1976

NOTE: Casing left in hole.
11 ft. of 4" surface (0-11'),
523 ft. of NX (1448-1971'),
697 ft. of BX (2500-3197')

DACITE

EARLIER VOLCANICS

Andesite-basalt flows of 15-50' thickness with rubble and/or oxidized tops.

WHITETAIL CONGLOMERATE

Sandy to gritty lenses and matrix with tuffaceous lenses, with clasts of pre-Whitetail units. Minor Cu°.

2213-2400' Muddy light brown to light green matrix 42 %.
Clasts: 95 % sc, 5 % p€ qtzite.

2400-2850' Medium green to green-brown matrix 30 %.
Clasts: 77 % sc, 21 % db, 2 % p€ qtzite.

2850-3226' Medium brown to red-brown at base, matrix 25 %.
Clasts: 66 % sc, 20 % db, 13 % Schultze and porphyry, 1 % p€ qtzite, tr Tbx. (numerous alt. clasts)

SLIDE BLOCK of Pinal Schist intruded by Laramide granitic aplite.

Altered and hematite replaced schist breccia, with minor gouge and "matrix" zones. Oxidized with tr. Cu° (Leached Capping).

-3774-3777' Basal fault and gouge zone, oxidized, slickensides. @ 15°-20°

PINAL SCHIST, *cut by Laramide biotite feldspar porphyry (Lbfp)*

Top portion oxidized with FeOx and containing remnant chalcocite in quartz-sericite alteration.

Lbfp at 3879-3885' is a 30° dipping structure with gouge at top and bottom.

Sulfide zone is variably altered with quartz-sericite bands following schistosity at 10°-20° and cut across at 30°-60°. Bands also cut Lbfp.

Mineralization, disseminated and thin veins, follow schistosity and cut across at 60°. Most quartz-sulfide veins (q.s.v.) cut at 60°. Chalcocite is main copper sulfide to 3958 where bornite appears and becomes dominant below with continued chalcocite.

Schist contains numerous crushed-gouge zones with chalcocite-bornite.

Minor pyrite throughout with trace of chalcopyrite appearing at bottom of hole.

NOTE: Individual assays are found in Assay Report dated Feb. 10, 1977.

T. 1 S., R. 13 E.
NW 1/4 SW 1/4 SW 1/4 of Sec. 23

GRAPHIC LOG & ASSAY RESULTS
of
DRILL HOLE A-8
SUPERIOR EAST PROJECT
PINAL COUNTY, ARIZONA
SCALE 1" = 300'

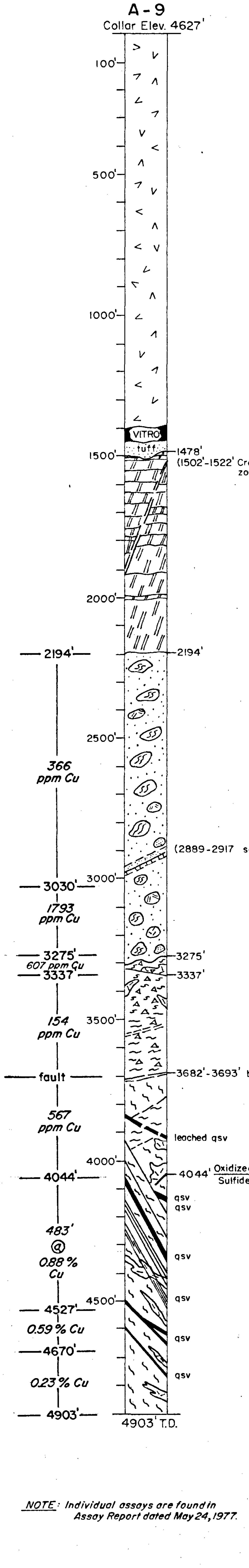
J.D.S.
Feb. 1977
MVK 2486-K

ASARCO DRILL HOLE A-9

CORE: Surface - 2357' NC
2357'- 3624' NX
3624'- 4903' BX
T.D.

Joy Manufacturing Co.
Joy-22, Heavy Duty Rig
Jan. 7 - May 4, 1977

NOTE: Casing left in hole:
10' of 4"; Surface-10'
464' of NX; 1893'-2357'
586' of Bx; 3038'-3624'



DACITE

EARLIER VOLCANICS

Andesitic - basalt flows, 5' - 45' thick, with few 100' - 200' thick units, separated by rubble and/or oxidized tops.

Cross - fault probably has around 100' feet of vertical offset, with dominant horizontal component (- 20° slickensides).

WHITETAIL CONGLOMERATE

Clasts, few qmp & blk qm, set in sandy, gritty, granular, tuffaceous matrix. Minor Cu°.

2194'-2600' M: 19 % brown to tan and green brown.
ACP: 97 1/2 % sc, 2 1/2 % db

2600'-2889' M: 23 %, brown to green brown to green.
ACP: 65 % sc, 25 % db, 10 % pЄ qtz & Pioneer.

(2889-2917 sandy-grit of db & gr debris; w/ fresh water lms unit)

2917' - 3000' M: 17 1/2 %, chocolate to dark brown
ACP: 54 % sc, 45 1/2 % Schultze gr, 1/2 % db.

3000'- 3275' M: 17 % dark brown w/ reddish cast
ACP: 65 % sc, 21 % db, 11 % Schultze,
3 % Єqtzite minor leached clasts.

SLIDE BLOCK of M-1A Type. Lqm w/ chilled borders intruding pЄ schist. Both cut by qtz veins. Totally oxidized. Broken w/ 10-40 % red-brown "adobe" matrix. Rests on 45 % slip surface.

SLIDE BLOCK of A-2 Type. Broken, sheared, gougy, brecciated pЄ schist w/ few brecciated Lqmp dikes. "Leached Capping" w/ tr to 2 % limonite, minor cuprite & black hematite above fault at 3521'-3539'. 10 % - 40 % hematite below fault. Quartz-sericite & qtz veining throughout.

3682'-3693' basal fault zone at 10°

PINAL SCHIST w/ minor granite aplite dikes. Minor hematite, 1 % - 5 %, mainly along schistosity. Cut by inclined breccia zones & quartz - sericite bands w/ remnant chalcocite (3900) also qtz veining at 60°. Schistosity changes across minor faults.

PINAL SCHIST w/ minor porphyry & biotite feldspar porphyry dikes.

qsv, quartz sulfide veins, w/ weakly developed quartz masses, often brecciated w/ crushed bornite - chalcocite & pyrite.

Intense quartz - sericite banding subparallel to the 45° - 60° qsv zones & subparallel to schistosity at 5° - 30°.

Breccia & gauge zones throughout in similar orientation.

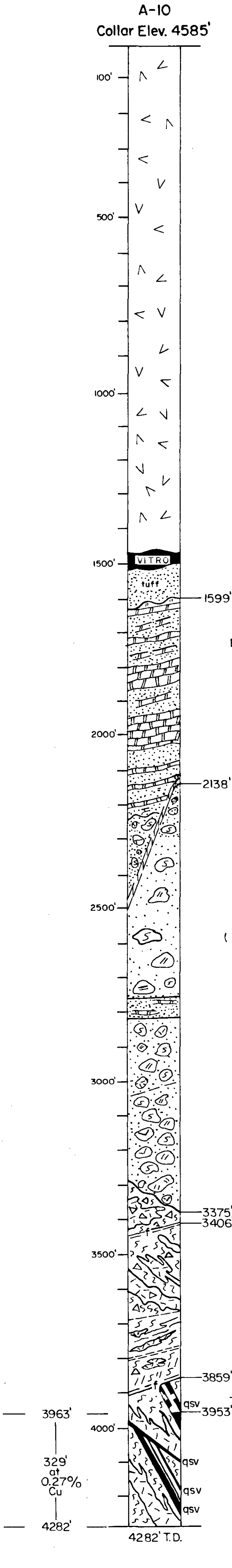
NOTE: Individual assays are found in Assay Report dated May 24, 1977.

T. 1 S. R. 13 E.
SW 1/4 NW 1/4 SW 1/4 of Sec. 23

GRAPHIC LOG & ASSAY RESULTS
of
DRILL HOLE A-9
SUPERIOR EAST PROJECT
PINAL COUNTY, ARIZONA
SCALE 1" = 300'

J.D.S.

May 1977
ALR 2486-M



ASARCO DRILL HOLE A-10

Joy Drilling Company
Joy Heavy Duty HD-22
May 5 - August 3, 1977
November 15 - December 28, 1977
5" rock bit surface - 11'
NC core 11' - 2437'
NX core 2437' - 3417'
BX core 3417' - 3968'
AX core 3968' - 4282' T.D.
NOTE: Casing left in hole,
11' of 4.5" surface - 11',
141' of NX 2296' - 2437',
222' of BX 3195' - 3417'
also BX rods from 3380' - 3968'

DACITE. Medium chocolate brown to dense orange brown to olive brown.

Fragmental content increases

Vitrophyre unit 1468' - 1492'

Crystal tuff, brown at top grading to grey at base

EARLIER VOLCANICS. Dense green block andesitic-basalt flows with oxidized tops, vesicular, with increasing red and red-black cinder ash towards base of total unit. Flows dip up to 25°. Individual units of cinders and flows vary from 70 - 150 in thickness.

2114' - 2117', Steep angular shearing cross fault

WHITETAIL CONGLOMERATE

2138' - 2230'.	M: 26.5% dark brown to grey green, sandy grit ACP: 51.5% sch, 39.5% p€sed, 5% p€gr, 2.5% db, 1% Paleozoic, dipping 5-10°
2230' - 2390'	M: 82% green to green grey brown with tuff lenses 10° ACP: 89% sch, 9% p€sed, 2% db, trace of p€gr and Paleozoic
2390' - 2752'	M: 20.5% brown to green brown, sandy grit ACP: 71% sch, 24% db, 4% p€sed, and 1% bolsa with fresh-water lime
(2752' - 2814')	Mixture of limey siltstone-mudstone and fresh-water lime with 52.5% green brown matrix and grit of 61.5% sch, 26% Schultze border, 11.5% db, and 1% p€sed at 5°-10°
2814' - 3375'	M: 19% dark to reddish brown, sandy grit ACP: 76.5% sch, 15% db, 6.5% Schultze and blk porphyry, 2% p€sed with minor Cu°, dipping 20°-40°

M-1A TYPE S.B. 83% border Schultze and 23% schist in 23% matrix of brick-red sandy grit. Rests on 15°-20° fault surface. Totally oxidized.

A-2 TYPE S.B. Broken and crushed units of Pinal schist cut by Laramide biotite feldspar and Laramide black porphyry. Qtz-sericite and biotitizations of units with remnant cuprite and chalcocite. Totally oxidized. Cut by flat faults.

(basal fault zone at 20°)

PINAL SCHIST Cut by a number of Laramide quartz feldspar porphyry and black porphyry dikes and sills. Units cut by quartz-sericite bands with disseminated and vein mineralization at 30°-60°.

oxidized
sulfide

NOTE: Individual assays are found in ASSAY REPORT dated January 13, 1978

T. 1 S. R. 13 E.
NW 1/4 SE 1/4 SE 1/4 of Sec. 22

GRAPHIC LOG & ASSAY RESULTS
of
DRILL HOLE A-10
SUPERIOR EAST PROJECT
PINAL COUNTY, ARIZONA
SCALE 1" = 300'

J.D.S. Jan., 1978

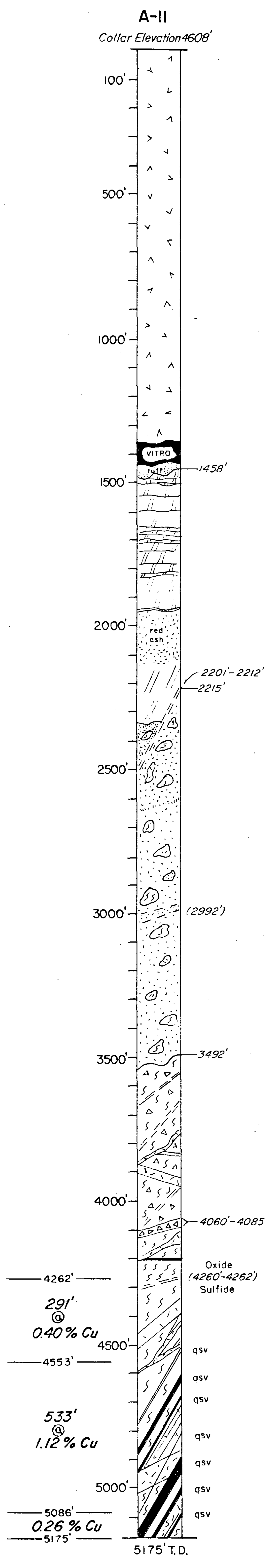
mn 2486-o dam

ASARCO DRILL HOLE A-11

CORE: Surface - 2580' NC
2580'-3772' NX
3772'-4857' BX
4857'-5175' AX

Joy Manufacturing Co.
Joy-22, HD
Surface-5175'
8/2/78-6/20/79

NOTE: Casing left in hole
137 of 4"; Surface (0-137')
2550' of NX Casing (30'-2580')
840' of BX Casing (2932'-3772')
1102' of AX Casing, ie BX Rods, (3755-4857')
(including barrel & bit)



DACITE

EARLIER VOLCANICS

Andesitic basalt flows of 6-283' in thickness with rubble or oxidized tops. Lower flow has 187' of red ash underlain by 96' of blue black basalt of "Olberg ash & Blue Basalt" type.

WHITETAIL CONGLOMERATE

Sandy to gritty matrix lenses, with lenses of tuffaceous material, containing clasts of pre-Whitetail units. Minor Cu°.

2215-2601' red, muddy brown w/greenish matrix 35 %
Clasts: 98 ½ sc, 1 db, ½ Schultze
2601-2607' tuff bed
2607-2960' dark brown to dirty green matrix 24 %
Clasts: 77sc, 18 db, 5 Apache
2960-2992' sandy grit w/schist & diabase debris
2992-3060' mud red brown matrix 32 %
Clasts: 49 Schultze, 41 sc, 7db, 3 Apache
3060-3492' dark red to orange red matrix 19 %
Clasts: 73 sc, 20 db, 7 Schultze, tr Apache

SLIDE BLOCK of Pinal Schist intruded by Laramide biotite feldspar porphyry & diorite porphyry dikes Altered & hematite replaced gouge-bx zones with minor Cu°. Oxidized, leached capping.

PINAL SCHIST cut by Laramide biotite feldspar porphyry dikes.
Top portion oxidized, leached capping, w/oxidized qsv zones, tr native copper remaining, probably a moved block in part. 15° fault zone @ 4260-4262' is oxide-sulfide contact.

Sulfide zone contains disseminated py-cc-bn & quartz-sulfide veins (py-bn) in quartz-sericite altered wallrock, bands, & breccia zones, generally at + 60° inclination.

NOTE: Individual assays are found in Assay Report dated July 13, 1979

T. 1 S. R. 13 E.
NW ¼ NW ¼ SW ¼ of Sec. 23

GRAPHIC LOG & ASSAY RESULTS
of
DRILL HOLE A-11
SUPERIOR EAST PROJECT
PINAL COUNTY, ARIZONA
SCALE 1" = 300'

J.D.S.

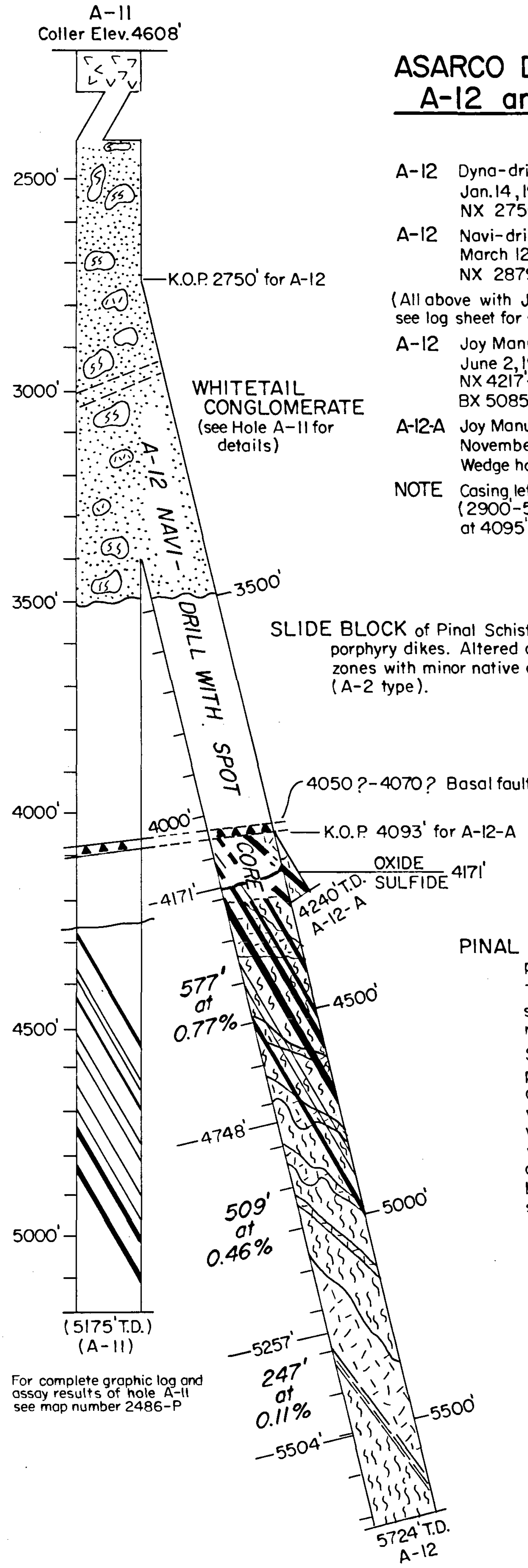
Aug. 1979
MVK 2486-P

ASARCO DRILL HOLES A-12 and A-12-A

A-12	Dyna-drill, Thompson & Associates Jan.14, 1980 – March 5, 1980 NX 2750' – 2879' (terminated)
A-12	Navi-drill, Christensen (Boyles) March 12, 1981 — June 1, 1981 NX 2879' – 4217'

(All above with Joy Manufacturing Company drillers; see log sheet for spot cores)

A-12	Joy Manufacturing Company June 2, 1981 – November 10, 1981 NX 4217' – 5085' BX 5085' – 5724' T.D.
A-12-A	Joy Manufacturing Company November 11, 1981 – December 19, 1981 Wedge hole, BX 4093' – 4240' T.D.
NOTE	Casing left in Hole A-12, 2185' of BX casing (2900'-5085'), and wedge of A-12-A set at 4095' (base)



WHITETAIL CONGLOMERATE (see Hole A-11 for details)

SLIDE BLOCK of Pinal Schist intruded by Laramide biotite feldspar porphyry dikes. Altered and hematite replaced gouge-breccia zones with minor native copper. Oxidized, leached capping (A-2 type).

PINAL SCHIST cut by Laramide feldspar porphyry dikes at 45°-60°.

Top portion, 4070'?-4171', oxidized with some brecciation and faults, some oxidized remnant chalcocite and native copper.

Sulfide zone contains disseminated py-cc-bn and qtz-cc-bn veins, changing below 4750' to qtz-py-cp-bn veins and below 5050' to qtz-py-cp veins decreasing with depth. All in variable quartz-sericite alteration veins and halos with some K-spar type below 5300'. Numerous breccia and shear zones throughout.

For complete graphic log and assay results of hole A-11 see map number 2486-P

NOTE: Individual assay for hole A-12 and A-12-A may be found in assay report dated January 15, 1982.

T. 1 S., R.13 E.
NW¼ NW¼ SW¼ of Sec.23

GRAPHIC LOG & ASSAY RESULTS
OF
DRILL HOLES
A-12 and A-12-A
SUPERIOR EAST PROJECT

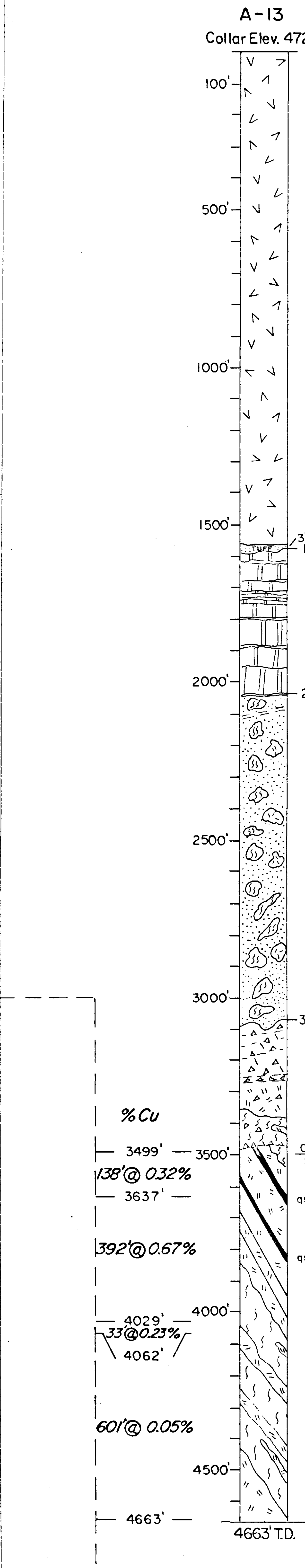
PINAL COUNTY, ARIZONA
SCALE 1" = 300'
J.D.Sell Jan.1982
mn 2486s dam 1/82

ASARCO DRILL HOLE A-13

CORE: Surface — 10' — (6¼ RB)
10' - 2363' NC
2363' - 4663' NX

Joy Manufacturing Co.
Joy-36, TM.
Surface -4663'
March 8, 1980 - Sept. 8, 1980

NOTE: Casing left in hole
4": Surface -10' (w/cap)
NX: 1723' - 2363' (640')



DACITE

3' of vitrophyre
1580

EARLIER VOLCANICS
Andesitic basalt flows with oxidized tops, autobrecciation.
All portions generally fractured.

2036'

WHITE TAIL CONGLOMERATE
1"-4" subangular clasts set in gritty-sandy matrix.
Minor Cu° below 2250'; tuff lense @ 10°-15° (2090')

2036'-2070'	M : 35%, med. dark brown, reddish cast. ACP: 65%; 100 sc
2070'-2285'	M : 21%, green grey to green brown. ACP: 79%; 88 sc, 12 db
2285'-2600'	M : 15%, med. brown to green brown. ACP: 85%; 70 sc, 28 db, 2 p€ sed.
2600'-3071'	M : 20%, red brown. ACP: 80%; 95 sc, 5 db

3071'

A-2 TYPE SLIDE BLOCK of Pinal Schist cut by high angled qtz-seri bands w/1-2% hematite limonite w/numerous flattish breccia & gouge zones throughout.

(3242'-3260') Flattish breccia-gouge; possibly basal fault zone.

PINAL SCHIST & MONZONITE, broken brecciated & gougy to 3471; but all cut by variable quartz-sericite-sulfide (or oxidized) bands in overall strong quartz-sericite alteration. Bands & breccia zones generally at steep, +60° angle to core axis.
Quartz-sulfide veins & breccias.

OXIDIZED / SULFIDE 3499'

qsv

qsv

NOTE: Individual assays are found in Assay Report dated Aug. 5, 1981.

T. 1 S. R. 13 E.

SW¼ SW ¼ SE ¼ SW ¼ of Sec. 23

GRAPHIC LOG & ASSAY RESULTS
of
DRILL HOLE A-13
SUPERIOR EAST PROJECT
PINAL COUNTY, ARIZONA
SCALE 1" = 300'

J.D. Sell
Aug. 1981
MVK-2486 Q

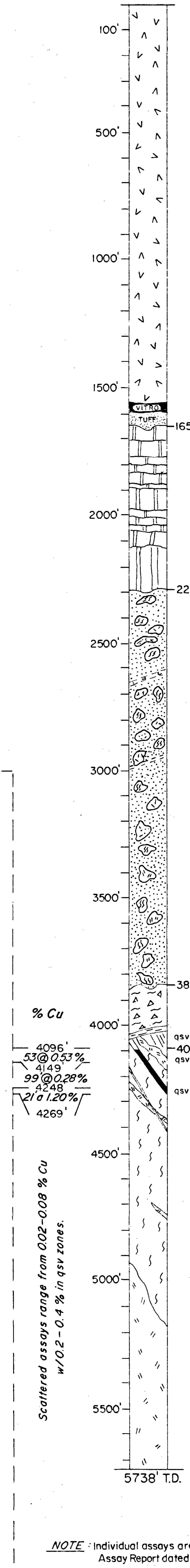
ASARCO DRILL HOLE A-14

ROTARY: Surface - 1534'
8": Surface - 20'
6": 20'-1534'
CMX DRILLING CO.
June 20,1980 - July 2,1980

CORE: 1534'-2891' NC
2891'-5493' NX
5493'-5738' T.D. BX
JOY MANUFACTURING Co.
Sept. 19, 1980 - March 9, 1981

NOTE: Casing left in hole:
7': Surface - 20'
4 1/2: Surface - 1534'
NX: Surface - 2891'
BX: 3750'-5493 w/shoe
Six sack Portland cement plug set at 3000'.

A-14
Collar Elev. 4694'



DACITE

EARLIER VOLCANICS

Andesitic basalt flows of 5' to 162' overlain by oxidized rubble-breccia tops of 6' to 60' for total thickness of flow units of 17'-168'

WHITETAIL CONGLOMERATE

1/2"-4" clasts set in gritty-sand matrix.
Minor Cu° below 2700 feet.

2289'-2325'	M: 53 %; dirty to tan brown. ACP: 47 %; 90 sc, 8 p€ sed, 2 p€gr.
2325'-2493'	M: 60 %; green tan to green grey. ACP: 40 %, 60 sc, 30 p€ sed, 10 p€gr.
2493'-2577'	M: 58 %; org-red-tan greenish with pumice zone at base. ACP: 42 %; 97 sc, 2 db, 1 p€ sed.
2577'-2728'	M: 10 %; dark brown w/ lense of fresh limestone @ 2630' ACP: 90 %; 85 sc, 15 db, tr p€ sed.
2728'-3000'	M: 20 %; dark to green brown. ACP: 80 %; 56 sc, 39 db, 5 p€ sed.
3000'-3487'	M: 15 %; med. dark brown. ACP: 85 %; 70 sc, 17 db, 8 p€ gr, 5 Lr. gr.
3487'-3841'	M: 20 %; brick red brown. ACP: 80 %; 92 sc, 8 Lr. gr, tr p€ gr.

A-2 TYPE SLIDE BLOCK of Pinal Schist w/altered bands & some aplite & qfp w/alteration-mineral. ALL OXIDIZED.

BASAL FAULT ZONE @ 10°-15° (4006'-4015'), gouge-bx.

PINAL SCHIST cut by aplitic porphyry & quartz-feldspar porphyry, all cut by steep dipping quartz-sericite bands containing variable amounts of chalcocite, chalcopyrite, & pyrite, Some hematite bands, pyrite increasing with depth.
1/8" - 1/4" vns & narrow bx zones w/cc end 4149'

Below 5150', secondary K-feldspar & green sericite became noticeable component in schist & bfp, porphyry; quartz-sericite banding with minor mineral became scattered.

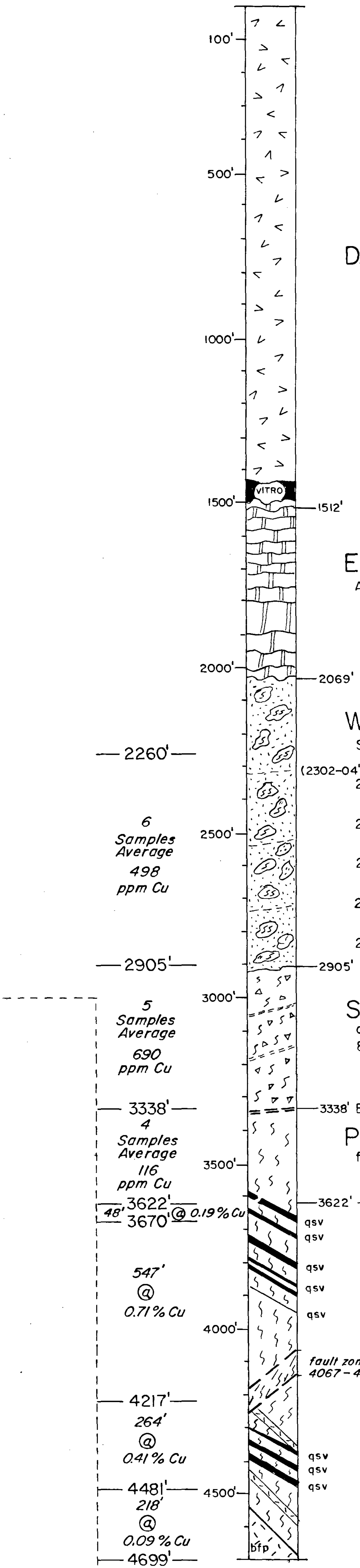
NOTE: Individual assays are found in Assay Report dated Aug. 10, 1981.

T. I S. R. 13 E.
N LINE of NW1/4 NE1/4 SE1/4 SE1/4 of Sec. 22

GRAPHIC LOG & ASSAY RESULTS
of
DRILL HOLE A-14
SUPERIOR EAST PROJECT
PINAL COUNTY, ARIZONA
SCALE 1"=300'
J.D. Sell
Aug. 1981
MVK-2486-R

A-15

Collar Elev. 4628'



4699' T.D.

ASARCO DRILL HOLE-15

Surface-11' Rock Bit 6'4"

CORE: 11-1101 NC
1101-2029 NX
2029-4699 BX

JOY MANUFACTORING CO.
JOY-22, Heavy Duty
Surface – 2029'
Feb. 16 – April 6, 1983
2029 - 4699 T.D.
April 2 – July 6, 1984

NOTE: Casing left in hole.
11' of 4" Surface (0-11')
650' of NX (441'-1101')
529' of BX (1500'-2029')

DACITE

EARLIER VOLCANICS

Andesite-basalt flows of 12'-98' thickness with rubble or oxidized tops.

WHITETAIL CONGLOMERATE

Sandy to gritty to muddy matrix with clasts of pre-Whitetail units. Minor Cu°

2069'-2302'	green tan grit matrix 25%, Clasts: 99+% sch, tr. qtzite, tr. db.
2302'-2304'	marker bed, fresh water lms w/ash grit matrix
2304'-2520'	green brown to brown matrix 27%, Clasts: 63% sch, 27% db, 8% qtzite, 2% p€ sh-lms
2520'-2720'	reddish muddy brown matrix 21%, Clasts: 76% sch, 22% db, 2% qtzite
2720'-2905'	reddish adobe to dark brown matrix 26%, Clasts: 65% sch, 18% db, 16% Lr gr porp, 1% p€ lms

SLIDE BLOCK

of A-2 type. Pinal schist, altered, oxidized leached capping type, with hematite, specularite, & some native copper. gouge-breccia zones throughout.

3338' Basal fault, subhorizontal, gouge-bx, 3334'-3338'

PINAL SCHIST

cut by minor Laramide biotite feldspar porphyry, (Lbfp), dikes.

3622' OXIDE / SULFIDE

Top portion oxidized of very poor leached capping characteristics which continues to 3670' where the first 45° dipping structures with cc-bornite is encountered.

Sulfide zones of bx-gouge bordering qtz-sericite and qtz veins with variable mineral content of cc-bornite, (qtz-sulf veins qsv) grading downward into cp below 4200' minor pyrite throughout. Zones dipping generally 30° or less.

NOTE: Individual assays are found in Assay Report dated Aug. 24, 1984

T. 1 S., R. 13 E.
NE 1/4, SW 1/4, SW 1/4 of Sec. 23

GRAPHIC LOG & ASSAY RESULTS

DRILL HOLE A-15
SUPERIOR EAST PROJECT
Pinal County, Arizona

SCALE: 1" = 300'

J.D. Sell July, 1984

MVK 2486-T

RAWHIDE PROJECT

ASARCO / INSPIRATION JOINT VENTURE

Hole AI-1

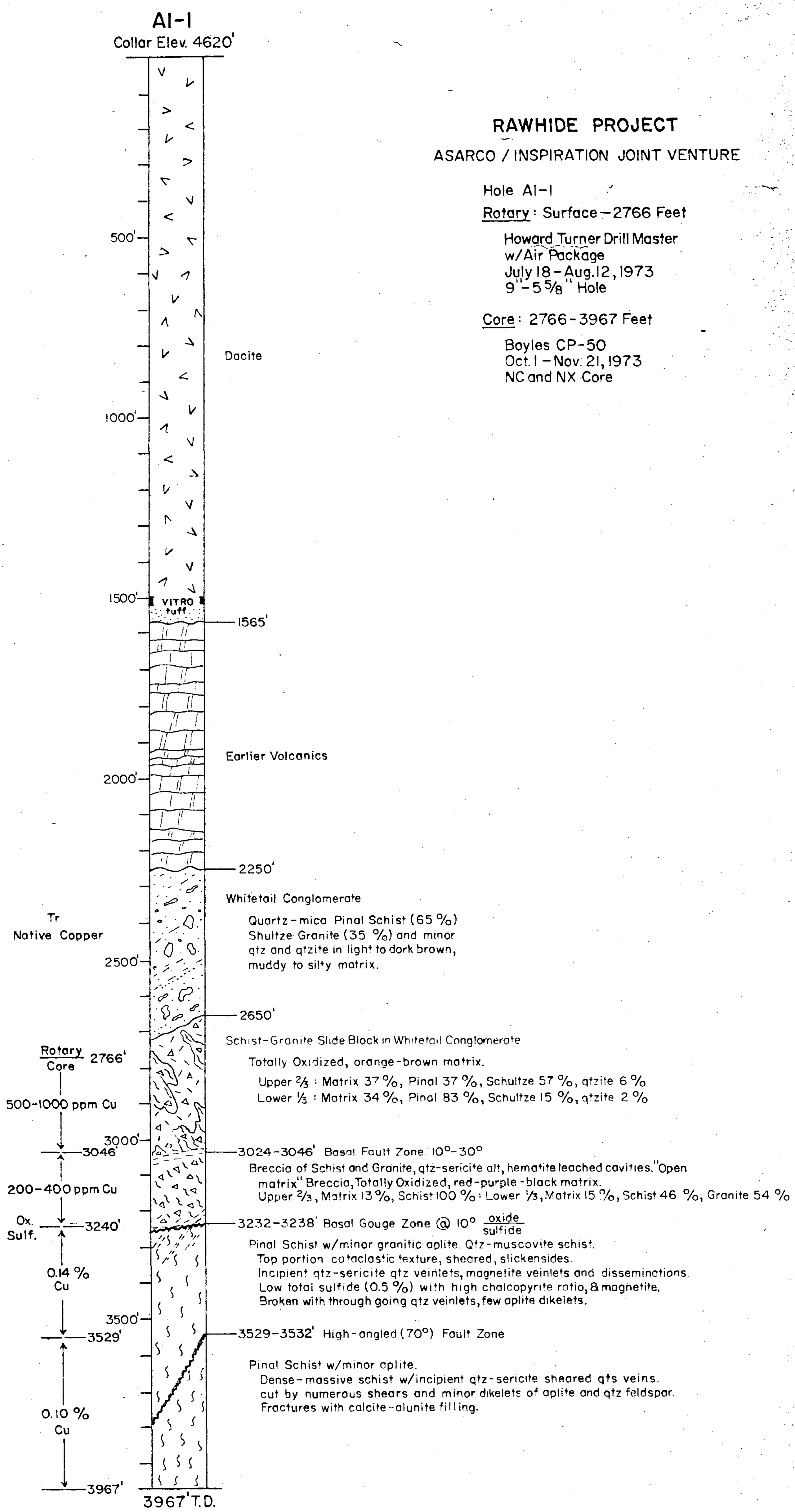
Rotary: Surface—2766 Feet

Howard Turner Drill Master
w/Air Package
July 18 - Aug. 12, 1973
9"- 5 5/8" Hole

Core: 2766-3967 Feet

Boyles CP-50
Oct. 1 – Nov. 21, 1973
NC and NX Core

AI-1
Collar Elev. 4620'



Dacite

Earlier Volcanics

Whitetail Conglomerate

Quartz-mica Pinal Schist (65 %)
Shultze Granite (35 %) and minor
qtz and qtzite in light to dark brown,
muddy to silty matrix.

Schist-Granite Slide Block in Whitetail Conglomerate

Totally Oxidized, orange-brown matrix.

Upper ⅔ : Matrix 37 %, Pinal 37 %, Schultze 57 %, qtzite 6 %
Lower ⅓ : Matrix 34 %, Pinal 83 %, Schultze 15 %, qtzite 2 %

3024-3046' Basal Fault Zone 10°-30°

Breccia of Schist and Granite, qtz-sericite alt, hematite leached cavities. "Open matrix" Breccia, Totally Oxidized, red-purple-black matrix.
Upper ⅔, Matrix 13 %, Schist 100 % : Lower ⅓, Matrix 15 %, Schist 46 %, Granite 54 %

3232-3238' Basal Gouge Zone @ 10° $\frac{\text{oxide}}{\text{sulfide}}$

Pinal Schist w/minor granitic aplite. Qtz-muscovite schist.
Top portion cataclastic texture, sheared, slickensides.
Incipient qtz-sericite qtz veinlets, magnetite veinlets and disseminations.
Low total sulfide (0.5 %) with high chalcopyrite ratio, & magnetite.
Broken with through going qtz veinlets, few aplite dikelets.

3529-3532' High-angled (70°) Fault Zone

Pinal Schist w/minor aplite.
Dense-massive schist w/incipient qtz-sericite sheared qts veins.
cut by numerous shears and minor dikelets of aplite and qtz feldspar.
Fractures with calcite-alunite filling.

Summary of Weighted Averages in Sulfide Intercept:

3240-3529', 289 feet @ 1381 ppm Cu, 9 ppm Pb, 52 ppm Zn, and 31 ppm Mo.
3529-3967', 438 feet @ 990 ppm Cu, 18 ppm Pb, 57 ppm Zn, and 21 ppm Mo.

3240-3967', 727 feet @ 1145 ppm Cu, 14 ppm Pb, 55 ppm Zn, and 25 ppm Mo.

T 1 S, R 13 E.

SE 1/4 SW 1/4 NE 1/4 of Sec. 23

GRAPHIC LOG & ASSAY RESULTS of DRILL HOLE AI-1

RAWHIDE PROJECT
(ASARCO / ICC Joint Venture)
Pinal County, Arizona
SCALE: 1"=300'
JDS Jan. 8, 1974
MVK 2700-X

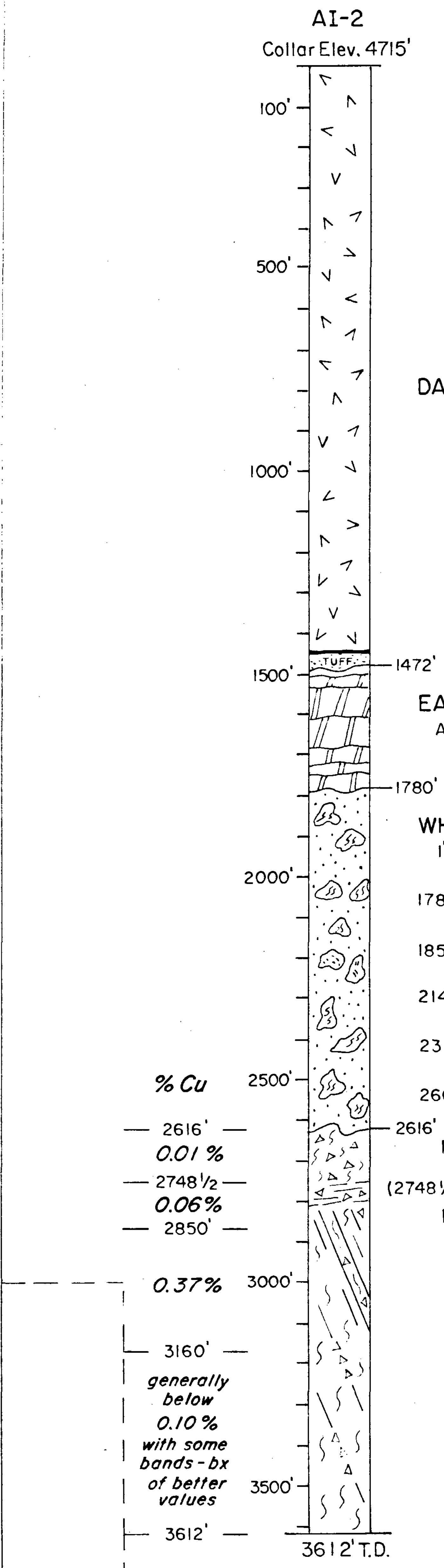
ASARCO DRILL HOLE AI-2

Surface — 3' — (6¼"RB)

CORE:
3' - 1961' NC
1961' - 2831½' NX
2831½ - 3612' BX

Joy Manufacturing Co.
Joy-22, HD.
Surface - 3612'
April 1, 1980 - Sept. 8 1980

NOTE: Casing left in hole
4": Surface - 3' (w/cap)
NX: 1600' - 1961' (361')
BX: 2420½ - 2831½
(411' including 5' NXE
core barrel, bit, & shell)



DACITE

EARLIER VOLCANICS
Andesite basalt flows with oxidized tops, some reddish, some autobrecciated & gas bubbles.

WHITETAIL CONGLOMERATE
1"-3" clasts of pre-Tw, subangular, set in matrix of sand and grit of same.

1780'-1859'	M: 30 % red brown to gray brown. ACP: 99 % sc (15 % alt.), tr db, tr p€gr.
1859'-2140'	M: 30 % light grey green to med. brown. ACP: 70 sc, 30 db, tr dsq, gr.
2140'-2322'	M: 25 % greenish brown to lgt. med. brown. ACP: 60 sc, 35 db, 5 dsq.
2322'-2603'	M: 35 %, brick red to adobe brown. ACP: 87 sc, 12 db, 1 p€gr, tr dsq.
2603'-2616'	M: 55 %, reddish brown. ACP: 99 sc, 1 p€gr.

PINAL SCHIST, oxidized, hematite-specularite, steep breccias, sulfides below 2709'.
(2748½'-2794') Basal Fault Zone @ flattish bx angles; sulfides.

PINAL SCHIST, oxidized to partially oxidized to 2920', sulfides to 3030', remainder partially oxidized. Better quartz-sericite alteration bands in better mineral zones. Breccias, steep angles throughout. Weak K-spar veining extends from 3150' to end of hole.

NOTE: Individual assays are found in Assay Report dated Aug. 14, 1981.

T. 1 S. R. 13 E.
SW¼ NE ¼ SW ¼ SE ¼ of Sec. 23

GRAPHIC LOG & ASSAY RESULTS
of
DRILL HOLE AI-2
RAWHIDE PROJECT
PINAL COUNTY, ARIZONA
SCALE 1" = 300'
J.D. Sell June 1981

MVK-2700 A

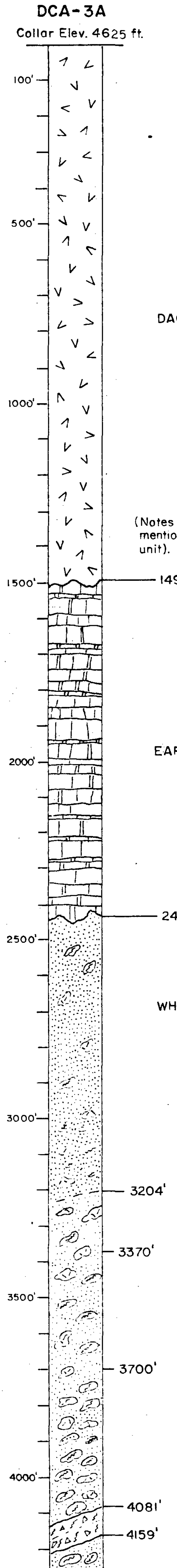
DRILL HOLE DCA-3A

ROTARY Miami Copper-Superior Oil
Surface-3000 ft.
Rotary-mud
May 7-June 21, 1965

CORE ASARCO
2980-5154 ft.
Boyles, CP-50
NX Core
July 2-October 16, 1974

NOTE: Core barrel & rods lost from 4150' to 4338'. Hole cemented up to 4089'. A new hole was deviated at 4089' and continued to terminal depth at 5154'.

Rotary information from files of Superior Oil Company.



DACITE

(Notes in SOC files do not mention vitrophyre or tuff unit).

EARLIER VOLCANICS

WHITETAIL CONGLOMERATE

Slightly muddy to very gritty matrix of fine debris with subangular to subrounded clasts, 1½"-2" medium size.

Matrix. red to muddy brown to chocolate brown at base, 18 %
Clast. Schultze 81 %, Pinal 16 %, Q.M. 3 %

Visible amounts of Cu° in chocolate brown matrix, 17 %
Clast. Schultze 64 %, Pinal 36 %, Q.M. trace.

dark brown matrix, 15 %
Clast. Pinal 61 %, Schultze 27 %, db 7½ %, Q.M 4½ %

dark brown to red brown matrix, 12 %.
Clast. Pinal 88 %, db 7 %, Q.M. 4 %, Ꞓqtzite 1 %

SLIDE BLOCK of crushed & broken Pinal Schist & Schultz Q.M., altered.
dip ± 20°

Tw brown-red matrix, 20 %
Clast. Pinal 97 %, Q.M. 3 %

SLIDE BLOCK of cataclastic Q.M. @ ± 30°

Tw, red-brown matrix 16 %. Clast. Pinal 95 %, Q.M 5 %

Cataclastic (moderate) fault slide of Schultze Q.M. (leached capping). altered w/silica flooding, some clay & sericite, variable iron, oxidized.

4666'-4670' Fault Gouge @ ± 20° OXIDE / SULFIDE

Schultze Q.M., broken, few shear zone; minor pyrite & moly.

4806'-4809' Fault Gouge @ 60°-70°

Pinal Schist w/minor gr. aplite squirts; cataclastic sheared.

4948'-4953' Fault Gouge @ ± 35°

Pinal Schist, broken but massive with fine pyrite, some magnetite. Abundant spider-web calcite filled fractures. Through going qtz veinlets.

Available Assays

ROTARY
2980'
CORE
427 ppm Cu
4081'
660 ppm Cu
4159'
2000 ppm Cu
4297'
826 ppm Cu
4394'
1225 ppm Cu
4454
3309 ppm Cu
Oxide 4666' 4690'
Sulfide
1250 ppm Cu
4806'
113 ppm Cu
4948'
106 ppm Cu
5154'

T 1 S, R 13 E
SW ¼ NE ¼ NW ¼ of Sec. 23

GRAPHIC LOG & ASSAY RESULTS
of
DRILL HOLE DCA-3A

SUPERIOR EAST PROJECT

GILA & PINAL COUNTIES, ARIZONA
SCALE 1" = 300'
J.D.S. July 8, 1974
MVK 2486-HH

JDS

3/31/94

Mr. Robert W. Schafer
Regional Manager
Western U.S. Exploration
BHP Minerals International, Inc
5330 South 900 East
Suite 200
Salt Lake City, Utah 84117

Superior East Project
Graphic Logs/Assays of
Drill Holes
Pinal Co., AZ.

Dear Bob:

I send you the following holes with the graphic log and assay results. Holes A-2, A-2W, A-8, A-9, A-10, A-11, A-12 + A-12A, A-13, A-14, A-15, AI-1, AI-2, and DCA-3A.

The location of the holes are on the attached drill hole-station map.

The completed hole A-16 and the short hole A-17 have not been drafted into this form.

Glad you are still interested.

Thanks for your comments on the paper.

Give me a call on anything else.

Sincerely
James D Sell

FILE

Porphyry Copper Deposits of the American Cordillera

Frances Wahl Pierce and John G. Bolm, Editors

Arizona Geological Society Digest 20
1995

656 pages

Discovery of a Deep (3500 feet) Unexposed Porphyry Copper Deposit at Superior East, Pinal County, Arizona

JAMES D. SELL *ASARCO Incorporated, Tucson, Arizona*

ABSTRACT

In 1970 ASARCO Incorporated initiated a search for porphyry copper mineralization postulated to lie under post-mineralization rocks between Superior and Miami in Pinal County, Arizona. An early drill hole penetrated 2,133 feet of volcanics and 4,351 feet of conglomerate for a total of 6,484 feet of post-mineralization cover rocks. Below the cover rocks the drill hole intercepted Laramide biotite quartz monzonite intruding Precambrian Pinal Schist which contained trace amounts of copper and molybdenum and displayed alteration and mineralization characteristic of porphyry copper deposits. Four drill holes later, the "discovery" hole penetrated 3,226 feet of post-mineralization rocks before intercepting the leached capping of a porphyry system. Below the leached capping, 646 feet of core assayed 1.57 percent copper. The intercept also averaged 31 ppm molybdenum, 0.22 ounces per ton silver, and trace gold.

Sulfide minerals at Superior East are chalcocite, bornite, chalcopyrite, and minor pyrite. Mineralization is disseminated and vein-controlled within Precambrian Pinal Schist intruded by several Laramide porphyries. Drilling in the deposit suggests a minimum geologic resource of 200 million tons with a grade of 0.90 percent copper including a high-grade core of 100 million tons at 1.1 percent copper.

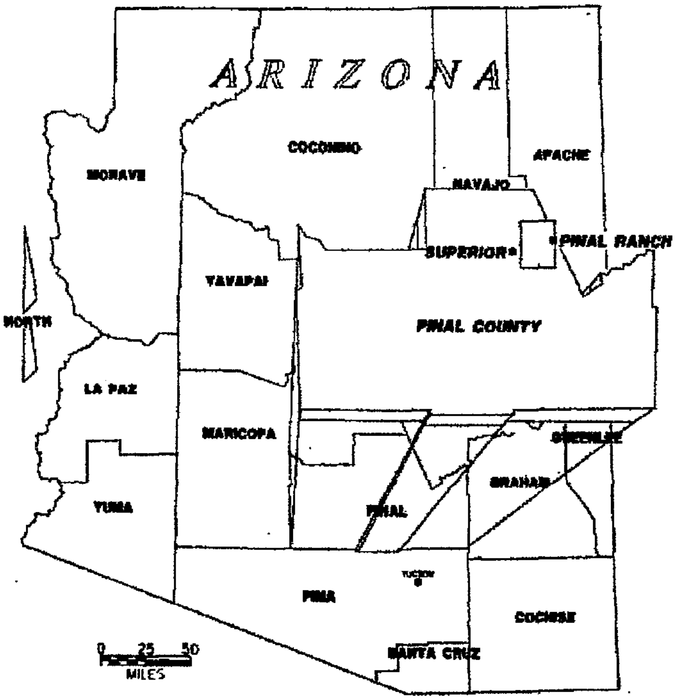


Figure 1. Location of Superior East Project, eastern Pinal County, Arizona

INTRODUCTION

The Superior East Project is located between Superior and Pinal Ranch west of Miami in eastern Pinal County, Arizona (fig. 1). U.S. Highway 60 bisects the area from east to west; Devils Canyon bisects the area from north to south.

The initial report (Sell, 1970) proposing exploration for a major porphyry copper deposit hidden beneath volcanic cover rocks between Superior and Pinal Ranch was accepted by ASARCO International's New York corporate office, and an initial appropriation of funds was advanced in 1970.

EXPLORATION CONCEPT

Mineral exploration trend

N.P. Peterson (1962) summarized the geology of the Globe-Miami-Superior Mineral Belt, a six-mile wide, thirty-mile long northeast-trending mineralized zone (fig. 2). He noted that nearly half the area between the Old Dominion Mine (Globe) to the northeast and the Magma Mine (Superior) to the southwest is covered by thick blankets of post-mineralization volcanics and basin-fill deposits.

Following Mayo (1958), Balla (1972) labeled the northeast-trending zone from Globe to Magma the Jemez Zone and noted that intrusive activity along this trend was evident at 1,420 Ma with renewed activity at 840 Ma. Between 70 Ma and 60 Ma a number of intrusives including the Schultze Granite dated from 62 to 58 Ma were emplaced along the zone. Intrusive activity resumed at 20 Ma with the emplacement of the Wood Camp Canyon Quartz Monzonite north of Superior.

The intrusive and structural histories of the region are summarized by Billingsley and Locke (1941), Gay (1972), Graybeal (1972), Hammer and Peterson (1968), Landwehr (1967), Lindgren

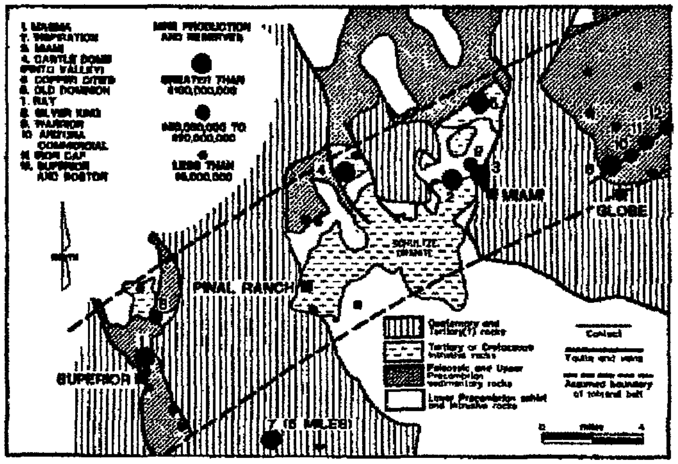


Figure 2. Index map of Pioneer (Superior) and Miami-Globe Districts with indicated limit of mineral belt and location of productive deposits (modified from N.P. Peterson, 1962).

(1915), Mayo (1958), Ransome (1915), Rehrig and Heidrick (1972), Schmitt (1933), and Wertz (1968). They also noted the alignment of intrusives and fracture trends related to porphyry copper deposits. This alignment and orientation is especially graphic on the geologic map of Arizona (Wilson and others, 1969).

The major pluton of the Superior East project area is the Schultze Granite (Peterson, N.P., 1962), which is elongated to the northeast. Castle Dome (Pinto Valley) and Copper Cities are along their own secondary northeast-trending alignment and are associated with smaller stocks of older (62-63 Ma, Balla, 1972) Lost Gulch Quartz Monzonite.

A large number of mineral deposits are associated with northeast elongation of plutons in the Arizona-New Mexico porphyry province. Deposits on northeast noses of such plutons include Poston Butte off the buried portion of the Three Peaks Granite (Balla, 1972), the Copper Creek Deposit (Hausen and Kerr, 1971, Balla, 1972), the Miami-Inspiration deposits off the Schultze Granite (Peterson, N.P., 1962; Olmstead and Johnson, 1966; Balla, 1972), the San Manuel Deposit (Creasey 1965; Thomas, 1966), the Johnson Camp, I-10, Dragoon, and Strong and Harris Deposits off the Texas Canyon Pluton (Cooper and Silver, 1964), the Metcalf-King Deposits in the Morenci District (Lindgren, 1905; Moolick and Durek, 1966), the Safford (Lone Star) Deposit (Cook and Robinson, 1962), and the Tyrone Deposit in New Mexico, (Paige, 1922).

Only the Sacaton Deposit north of Casa Grande is suggested to be off the southwest nose of the Three Peaks Monzonite (Balla, 1972). The location of twelve or so major mines off northeast noses and only one off a southwest nose of major northeast-trending plutons suggested an important question: What was the likelihood of a mineral deposit off the southwest nose of the northeast-elongate Schultze Granite under the volcanic cover between Pinal Ranch and Superior?

Schultze Granite Pluton

A.R. Marvin was a member of the Wheeler Survey which conducted geographical surveys west of the hundredth meridian in 1871. Marvin was attached to the group which went south from St. George, Utah, to the Gila River in Arizona. Marvin (1875) commented on the large orthoclase crystals which characterize the coarse-grained Schultze Granite.

A few ranchers, prospectors, and Indians roamed through the Schultze Granite canyons and spires before Ransome (1903) published his map of the Globe district and named the granite after the Schultze Ranch in the middle of the pluton. Ransome noted the irregular shape of the pluton with its general northeast elongation and several northwest-southeast lobes (fig. 2). Ransome noted the change in the Schultze Granite from its main part into "...a porphyritic facies which has been much fissured and altered, and is often conspicuously stained with salts of copper" on the northeast nose. He also observed the abundant sheeting or parallel fractures throughout the main part of the pluton. He made no comment concerning the southwestern end of the Schultze Granite, which is hidden under younger volcanic rocks.

Reed and Simmons (1962) separated the Schultze Granite from later porphyry intrusions in the northeast lobe. Creasey and Kistler (1962) reported a 58 Ma potassium-argon age for the mineralized porphyry nose of the Schultze Granite and a 62 Ma age for the Lost Gulch Quartz Monzonite.

In the Pinal Ranch quadrangle N.P. Peterson (1963) noted the large altered and weakly mineralized area on the southeast lobe of the Schultze Granite that trends toward Madera Peak. This zone was called the Madera Prospect, and several drill holes intersected minor chalcocite enrichment in low-grade pyrite-chalcopyrite mineralization. Clary (1970) called the altered zone the Santa Anna Anomaly.

Wertz (1968) proposed that the shape of the Schultze Granite in the form of a large cross was governed by two primary fault trends, one northeast and the other northwest. Fault mapping by N.P. Peterson (1962 and 1963), orientation of the Ellis Vein, and deflection of the southern porphyry dike (Ransome, 1919) all support the concept of structural control on the emplacement of the main northeast-trending Schultze Granite and its cross-trend lobes.

The abundance of large feldspars reported by Marvin (1875) prompted Kuellmer (1960) to use the Schultze Granite to study the compositional changes in the feldspars. Kuellmer noted evidence of late stage fractionation in the area of the altered and mineralized zones on the northeast nose and suggested a relationship between mineralization and magmatic differentiation. Two samples hint at a compositional change outside of the northeast nose (Kuellmer, 1960); one is from the southeast lobe near the Madera prospect, and the second is from a small dike north of Pinal Ranch where the southwest end of the Schultze Granite is covered by volcanic rocks.

Parry and Nackowski (1963) noted biotite from hydrothermally altered quartz monzonite stocks had higher copper values than did biotite from unaltered quartz monzonite stocks in the same areas of Nevada and Utah.

Clary (1970) conducted a study across the Schultze Granite using copper and sulfur values in ferromagnesian minerals. Clary's sample values outlined the Miami-Inspiration Mineral Zone on the northeast lobe, a 100 ppm bull's-eye in the center of the pluton, and a strong 2,000 ppm anomaly in the southeast terminus of the pluton at the Madera Prospect. One sample from the dike prong north of Pinal Ranch yielded 825 ppm copper in the bulk sample and 1,700 ppm copper in the ferromagnesian fraction.

The Schultze Granite was among three major plutons in Arizona investigated by Graybeal (1972). His study focused on trace element partitioning between coexisting orthoclase, plagioclase, biotite, and hornblende. Graybeal collected eight samples from the main phase of the Schultze Granite, none of which were from near the pluton's southwest contact with volcanic cover rocks. The distribution of trace elements in biotite in these samples confirmed the earlier studies indicating the copper content increased on the north and northeast sides of the Schultze Granite where the most significant mineralization is located.

The Schultze Granite is about five times as wide at its southwestern exposure at Pinal Ranch as at its northeastern end (fig. 2). This indicates that the pluton is terminated to the northeast before it reaches the Miami Fault, but there is no indication of closure to the southwest where the pluton is covered by volcanics.

Extended vein system to the northeast

The mineral belt between the Superior and Globe Districts (fig. 2) contains exposed mineralized blocks at Superior, Miami, and Globe. A deep alluvium-filled basin lies west of Superior, a volcanic-covered plateau lies between Superior and Pinal Ranch (the Superior East project area), and another deep alluvium-filled basin lies between Miami and Globe.

The most productive vein system in the northeastern Globe block runs from the Old Dominion Mine to the Superior and Boston Mine; nearly $200 million was produced from this vein system (Elsing and Heineman, 1936). The other mines in the Globe Block are on northeast-trending structures which form a vein swarm across the block. The basin-fill between Globe and Miami is over three miles wide and partly covers the Schultze Granite nose, associated porphyries, and the vein swarm in the Globe Block. A number of holes have been drilled in the basin, and some intercepted bedrock at a depth in excess of 4,000 feet (Peterson, N.P., 1962).

Mineralization is zoned from copper-molybdenum at Miami through copper-lead-zinc at the Old Dominion Mine to silver-rich structures at McMillanville north-northeast of Globe (Ransome, 1903). The northeast nose of the Schultze Granite, the copper porphyry deposits, and the swarm of veins to the northeast are believed to be closely related.

Extended vein system to the southwest

The Superior Block and Magma Vein System are located west of the volcanic cover rocks of the project area (fig. 2). The secondary northeast structural trend of the Copper Cities and Castle Dome Intrusives can be projected southwest to the Silver King Intrusive north of Superior. Potassium-argon dating of hornblende from the Silver King Intrusive produced an age of 22 Ma, which Balla (1972) believed to be a reset age and erroneous. The quartz diorite at Arnett Canyon west of Superior provided an age of 73 Ma, which Balla (1972) believed was also the correct age for the Silver King Quartz Diorite. Thus the ages of porphyry intrusives related to the three deposits on the northern secondary trend are slightly older than the quartz monzonite porphyry at Miami-Inspiration (58 Ma, Creasey and Kistler, 1962) and the suspected age of the undated porphyry dikes at the Magma Mine.

The Magma Mine is the most prolific producer in the Pioneer District, having produced almost continuously since 1911 (Hammer and Peterson, 1968). Veins at Superior include the Magma, Koener, South Branch, and Second South; all strike east-west across the N60°E trend of the mineral belt.

Other mines on veins with or without bedding replacement mineralization in the Superior Block include the Fortuna, Monarch of the Sea, Black Diamond, Baltimore, Magma Chief, and Apex; all are north of the Magma Veins (Short and others, 1943). Other mines to the south include the LS&A (Lake Shore & Arizona), Queen Creek, Cross Canyon, Belmont, Grand Pacific, and numerous small pits and short adits (Peterson, D.W., 1962). To the southwest are the rich silver veins of the Reymert and Silver Bell Mines. Only the LS&A, Queen Creek, Belmont, Reymert, and Silver Bell Mines had any significant recorded production (Elsing and Heineman, 1936).

Minor porphyry dikes are noted in the Superior Block (Hammer and Peterson, 1968), and the southwestern nose of the Schultze Granite is not known to occur in the eastern Magma Mine workings. The Magma copper-lead-zinc vein in the Superior Block, the accompanying vein swarm located along strike and to the southwest of the last known outcrop of Schultze Granite, and the location of the Reymert and Silver Bell silver mines to the southwest all suggested the possibility of a porphyry deposit under the Tertiary volcanic cover between the Magma Veins and the Schultze Granite.

Statistical suggestions

In the 1960s and early 1970s the use of statistics to evaluate potential for discoveries along covered trends was advanced by many authors (Lacy, 1961; Slichter and others, 1962; Weiss, 1969; Carson, 1969; Harris and Euresty, 1969). Some of these studies were aimed at helping management place a "firm handle" on reports by sometimes overeager exploration geologists.

Barnes (1971) examined 17 deposits on and 7 deposits off a 96 mile trend extending from the Old Dominion Mine to beyond Casa Grande. He related his findings back to the trend within the volcanic cover rocks between Magma and Pinal Ranch and suggested that five holes would intercept an alteration zone if it existed. He also predicted that another five holes would yield an ore intercept if a porphyry copper deposit was present.

TONNAGE AND GRADE OF DISTRICTS IN THE REGION

Review of deposits around Superior such as the porphyry deposits of Miami-Inspiration and Ray and the vein replacement deposits of Old Dominion and Magma indicated that this region contained substantial tonnages of exceptional grades which could be bulk-mined underground. These four deposits contained substantial tonnages of plus 1 percent copper mineralization, higher than most other porphyry deposits in Arizona which average less than 1 percent copper (Gilmour, 1982).

Table 1 lists early production-reserve-grade data for the four districts. The main objective of the Superior East project was to discover a deposit of the magnitude of the early years at the Miami-Inspiration and Ray Districts with the prospect of additional millions of tons of substantial grade such as has been continually produced from those districts. A secondary target was vein and limestone replacement mineralization such as had been produced at the Old Dominion and Magma Districts.

COVER ROCKS

Drilling during the Superior East exploration program revealed that cover rocks, which include both volcanic and sedimentary rocks of Tertiary age, range from about 2,000 to nearly 6,500 feet thick. The great thickness encountered in the drill holes was a surprise, because the total thickness of nearby surface outcrops of these same rocks is generally much less.

Cover rocks include dacite, vitrophyre, and tuff of the Apache Leap Tuff, earlier volcanic rocks, and the Whitetail Conglomerate. Based on geologic mapping between Apache Leap and Oak Flat, D.W. Peterson (1961) estimated a maximum thickness of about 2,000 feet for the Apache Leap Tuff; the greatest thickness penetrated in drill holes was actually 2,274 feet. Below the Apache Leap Tuff drilling encountered andesitic or basaltic lava flows that occupy the same stratigraphic position as rock units

Table 1. District and production-reserve grade

District/Mine	Date	Production-Reserve (Millions of Tons)	Grade (% Copper)
Miami			
Miami	1910-1931	140.5	0.99
Inspiration	1915-1931	152.6	1.34
Ray	1911-1931	131.4	1.62
Old Dominion	1881-1930	8.0	4.4
Magma	1914-1964	13.2	5.69

(Data from Bjorge and Shoemaker, 1933; Parsons, 1933; and Hammer and Peterson, 1968).

exposed in areas to the north and northwest which D.W. Peterson had called "earlier volcanic rocks" (1960) and "volcanic rocks" (1969). These exposed rocks are chiefly rhyolite and thin andesitic and basaltic flows that may be equivalent to widespread but discontinuous mafic flows in the surrounding region (Sell, 1968). The underlying Whitetail Conglomerate is a fluvial deposit laid down during Tertiary time in low-lying areas throughout the region. Although thin and discontinuous where exposed to the west beneath the Apache Leap Tuff, the Whitetail is thicker than 1,000 feet in several drill holes just a few miles from these outcrops. Its maximum drill-hole thickness of 4,578 feet far exceeds any known outcrop thickness in the region and includes a 45-foot-thick slide-block slab of diabase.

Apache Leap Tuff

The Apache Leap Tuff is a large ash-flow tuff sheet 19.4 to 20 m.y. in age (Creasey and Kistler, 1962; Damon and Bikerman, 1964). It initially covered nearly 1,000 square miles and had a volume of approximately 100 cubic miles. Figure 3 shows its outcrop distribution. This unit was first described by Ransome (1903), who thought it was mostly lava and called it "dacite" based on its phenocryst composition; it is actually a quartz latite chemically. D.W. Peterson (1961, 1968) described it as an ash-flow tuff based on the criteria of Smith (1960) and interpreted it as a single cooling unit. Subsequently he gave these rocks the formal name of Apache Leap Tuff (D.W. Peterson, 1969). It rests on earlier volcanics to the northwest and on the Whitetail Conglomerate elsewhere away from the edges of the dacite plateau.

Earlier volcanic rocks

The basaltic or andesitic rocks encountered in drill holes beneath the Apache Leap Tuff and above the Whitetail Conglomerate consist of single or multiple lava flows commonly indicated by the presence of rubbly zones of reddish oxidized rock. Vesicular rock with vesicles as much as 5 mm in diameter is common in these rubbly zones, but away from the rubbly zones the rocks are uniform, dense, and largely aphanitic with few to no phenocrysts.

The exposures of earlier volcanic rocks nearest to the southwesternmost exposure of the Schultze Granite are 3 to 7 miles north of Superior (fig. 3; Peterson, D.W., 1960, 1969). These exposures consist largely of rhyolitic lava flows and tuffs with thin andesitic and basaltic lava flows near their bases. The thin andesitic and basaltic flows probably correlate with mafic rocks penetrated in drill holes. Radiometric dates have not been obtained for the earlier volcanic rocks that underlie the Apache Leap Tuff.

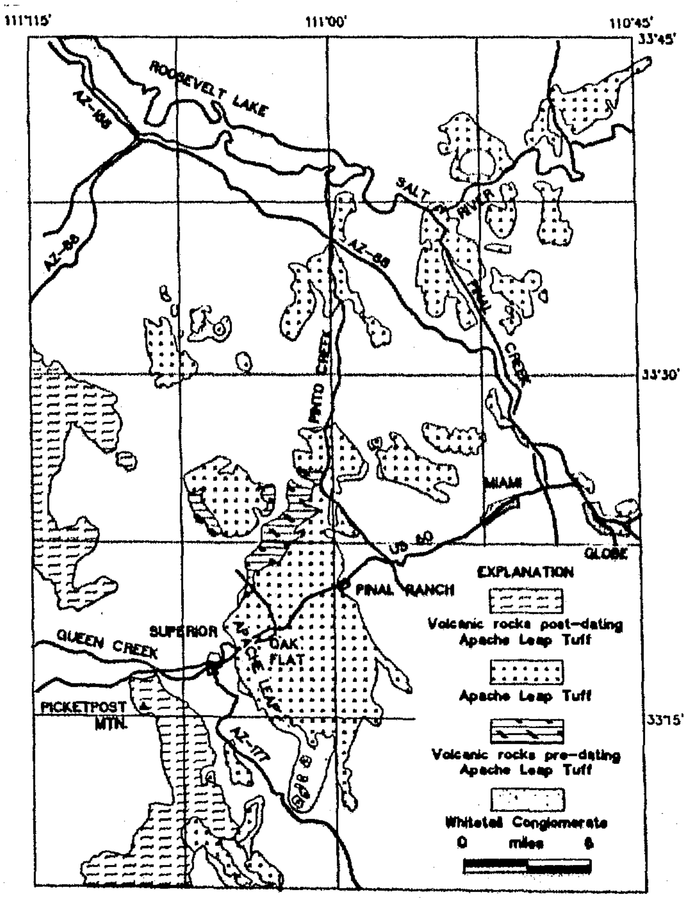


Figure 3. Map showing approximate outcrop distribution of the Apache Leap Tuff, volcanic rocks that post-date and pre-date the Apache Leap Tuff, and the Whitetail Conglomerate.

Whitetail Conglomerate

The Whitetail Conglomerate accumulated in low-lying areas during a period of erosion that preceded massive Tertiary volcanic eruptions (D.W. Peterson, 1962). The unit was first described by Ransome (1903) from areas west of Globe and Miami. Usage of the name subsequently spread, and the term is commonly applied to Tertiary fluvial deposits throughout the region. D.W. Peterson (1960, 1969) mapped local patches of channel-filling Whitetail Conglomerate in the Haunted Canyon and Superior quadrangles on the northwest and north sides of the Apache Leap plateau. None was mapped on the east side. At Teapot Mountain near Ray, Ransome (1919) mapped 800 feet of Whitetail Conglomerate under Apache Leap Tuff. A potassium-argon age of 32 Ma has been obtained from air-fall tuff inter-

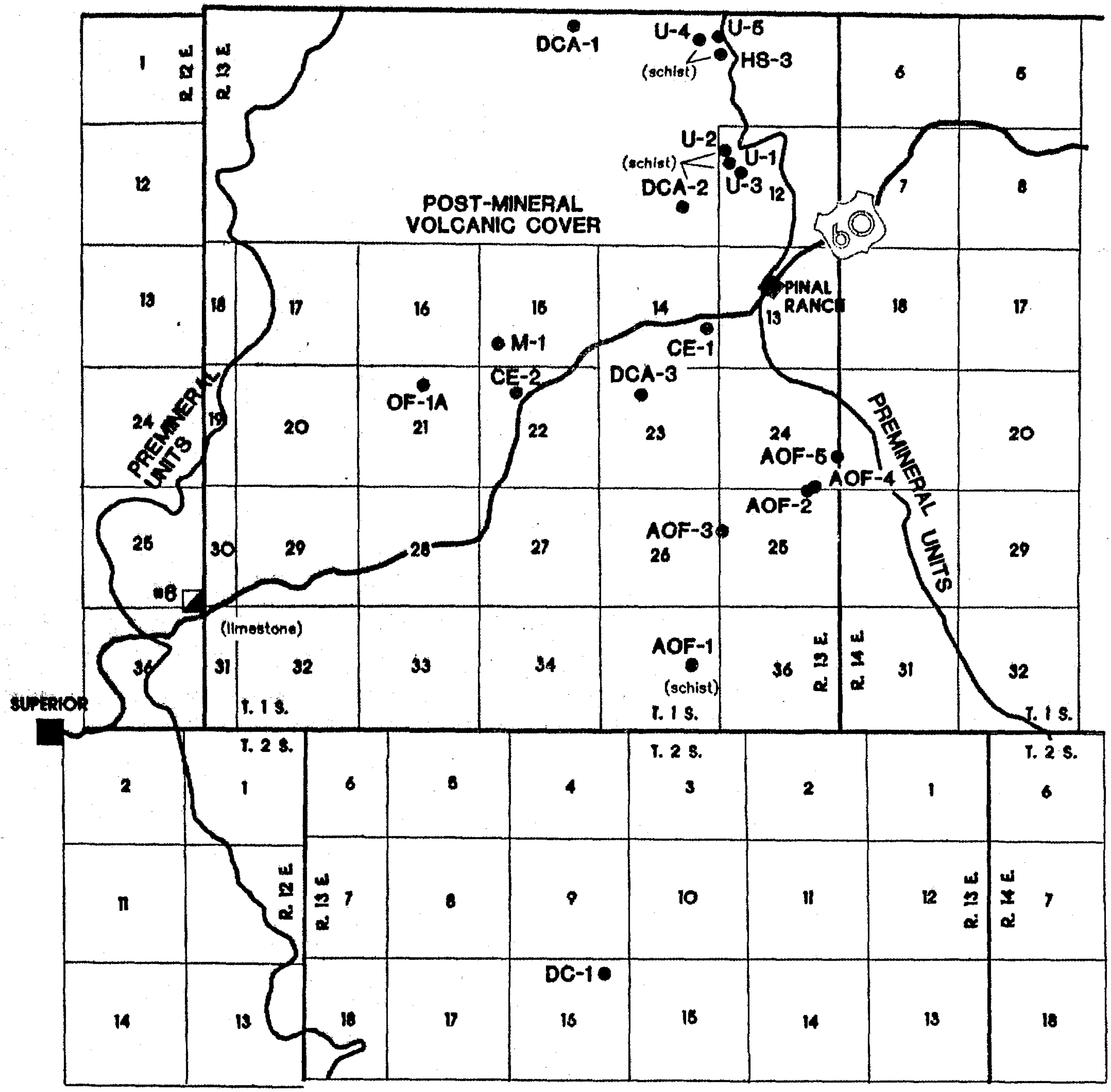


Figure 4. Drill hole location map, 1930-1970, with pre-mineral units penetrated.

bedded with the Whitetail at Ray (Cornwall and others, 1971). Clasts in the conglomerate are pre-Oligocene in age and vary in lithology depending on rock types exposed nearby at the time of deposition. Clasts range in size from pebbles to cobbles and reach boulder size in some places. The great thickness of the Whitetail in the area of this study suggests that it was deposited in a subsiding trough or basin. Paleozoic limestones underlie the Whitetail in drill holes west of Devils Canyon, while the Pinal Schist and units intruding it underlie the conglomerate east of the Canyon; large "slide blocks" from 48 to 433 feet thick are locally included in the conglomerate in this area. These blocks provide further support for the rapid subsidence of the basin.

EARLY DRILL HOLES COLLARED IN COVER ROCKS

By the end of 1970 a total of twenty-three holes (fig. 4; table 2) had been collared in the Apache Leap Tuff covering the plateau area between Superior and Pinal Ranch. Only nine holes

Table 2. Thickness of cover rock units, 1930-1970 data

Hole	Apache Leap Tuff	Early Volcanics	Whitetail Conglomerate	Pre-Mineralization Rock
No. 6 Shaft	670	none	580	lms
CE-1	2,200	650+ *	nr **	nr
CE-2	1,490+	nr	nr	nr
U-1	711	none	none	schist
U-2	737	none	none	schist
U-3	625	none	none	schist
U-4	1,235	none	none	schist
U-5	488	none	none	schist
HS-3	46	none	none	schist
DCA-1	1,420	790	1,801+	nr
DCA-2	1,340	none	185	schist
DCA-3	1,490	940	550+	nr
OF-1	671	nr	nr	nr
OF-1A	1,995	155+	nr	nr
DC-1	1,165	none	1,138+	nr
AOF-1	1,106	none	1,833	schist
AOF-2	780	none	2,278+	nr
AOF-3	122+	nr	nr	nr
AOF-4	864+	nr	nr	nr
AOF-5	1,030	none	725+	nr
I-6	1,650+	nr	nr	nr
Mw	200+	nr	nr	nr
M-1	1,890	512+	nr	nr

* + (Plus) signifies drilling stopped in unit.

** nr signifies unit not reached.

had penetrated the total package of cover rocks and reached the underlying pre-mineralization units. Six of these nine holes were near the northeast edge of the cover rocks.

Of the fourteen holes which did not penetrate the cover rocks, six stopped in Apache Leap Tuff, three stopped in earlier volcanics, and five stopped in Whitetail Conglomerate. These holes provided additional data on thicknesses to be expected in future drilling.

Review of the data suggested a minimum of 700 feet of Apache Leap Tuff just back from any of the edges of the basin thickening rapidly to more than 2,000 feet toward the center but with a possible thinning to around 1,200 feet at the center.

With 600 feet of earlier volcanics at Kings Crown, 512 plus feet in M-1, and 940 feet in hole DCA-3 (table 2), it is easy to visualize a thick section to the north with a rapid pinch-out to the east and south; volcanics were not mentioned in the Magma #6 shaft nor in holes AOF-1 and DC-1 in the central and southern areas.

In the drill holes, three holes bottomed in Whitetail Conglomerate after cutting thick sections of Whitetail, these being DCA-1 with 1,801 feet, AOF-2 with 2,278 feet, and DC-1 with 1,138 feet of conglomerate (table 2). It was expected that fault control and deep channel erosion would influence where Whitetail Conglomerate would be preserved under the plateau volcanic rocks.

Postulated bedrock under the cover rocks

The Schultze Granite and possibly related porphyries were expected under the cover rocks. Drill hole data suggested the Precambrian Pinal Schist underlay the eastern portion of the cover rocks (table 2). Mapping at Ray showed Precambrian rocks on the east side of Mineral Creek and parts of the Pennsylvanian Naco Formation on the west side. The Paleozoic sedimentary section continues north past Superior, and Paleozoic rocks were suspected to be present under the cover rocks to the west. The Paleozoic rocks dip 30 degrees east at Superior, and Pinal Schist crops out on the eastern side of the cover rocks.

North-trending normal faults at Ray bring Precambrian Pinal Schist on the east into contact with down-dropped Naco Limestone on the west. These faults are partly along the trend of the Devils Canyon and are similar in trend and pattern to most of the faults mapped by D.W. Peterson (1969) in the Apache Leap Tuff.

The primary exploration target was along the projected trend of the Schultze Granite and its wallrocks. Pinal Schist with diabase and possibly minor Precambrian sedimentary rocks were expected from the east edge of the dacite plateau westward. North-trending faults were expected to drop this package downward to the west, and it was thought that the east-dipping Paleozoic sequence would be encountered where such down-dropping was sufficient to prevent its erosion. The curvilinear Devils Canyon was suspected to reflect the final drop off.

ASARCO PRE-DISCOVERY EXPLORATION

The exploration goal was to find a porphyry copper deposit comparable to the others at Miami or Ray. The occurrence of exotic copper oxides was known in the Powers Gulch area north of Pinal Ranch. The holes of United Verde, Howe Sound, and DCA-2 (fig. 4) had extended the copper oxide zone to the west. Hole AOF-1 had encountered barren schist to the south and was considered beyond any porphyry source.

In the years 1971 to 1972 ASARCO drilled three holes to

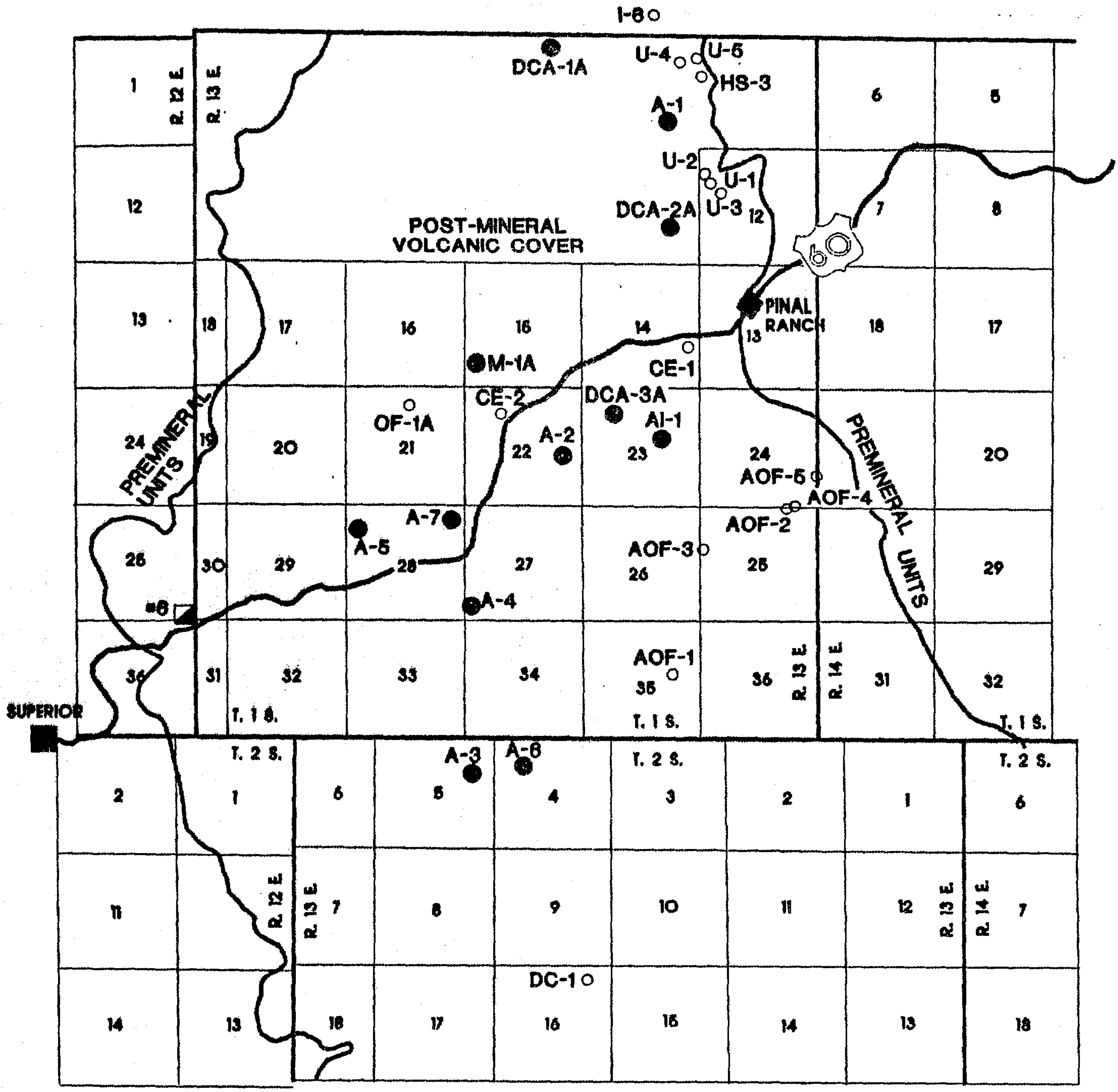


Figure 5. ASARCO drilling, 1971-1975.

completion, cased another for coring, and reentered and completed two holes which had been terminated in pre-mineralization units by other companies (fig. 5, appendix 1). Holes A-1 and renamed DCA-1A encountered copper oxide both in exotic slide blocks and in the apparent footwall schist. Low copper values from these holes were not of interest, but the amount of pyrite increased from hole A-1 toward DCA-2A suggesting an outer pyritic halo. Holes DCA-1A and M-1A (both renamed; fig. 5, appendix 1) had previously been drilled and were considered a low-cost look at bedrock in the central zone of the Apache Leap Plateau. Hole DCA-1A encountered the Naco Formation at great depth while hole M-1A found Permian Supai red-bed units. Permian rocks had not previously been reported in this part of Arizona. Hole A-5 was cased and waiting for a core rig.

Hole A-4 (fig. 5) was collared in the central portion of the cover rocks east of the Magma workings. This hole terminated at 6,664 feet (probably a BX-size record at the time) and encountered three important features: (1) a thick section consisting of three intervals in the lower part of the Whitetail Conglomerate totaling 567 feet of 0.95 percent copper occurring as native copper; (2) an oxidized slide block of Mississippian Escabrosa Limestone in the lowest Whitetail Conglomerate with alteration textures and mineralization typical of the Magma replacement body to the west, followed by in-place Escabrosa Limestone; and (3) a block of Pinal Schist intruded by quartz-eye biotite quartz monzonite porphyry. Plagioclase in the porphyry was moderately argillized and dusted with salmon-colored limonite and trace sulfides, and the wall rock was dusted with trace sulfides. A potassium-argon date of 62.4 Ma was obtained on biotite from the porphyry. All the data supported the view that this central area was within the fringes of a porphyry copper system.

Hole A-2 (fig. 5, appendix 1) was collared northeast of hole A-4 and mid-way in the southwest projection of the Schultze Granite. A Mayhew 3000 rotary rig rapidly pushed the hole to 4,078 feet. During this drilling a thin slab of quartz monzonite porphyry similar to one found in hole M-1A was cut within the Whitetail Conglomerate. The rotary hole was terminated when Pinal Schist chips, which appeared to have been intruded by quartz monzonite, were observed. These chips contained characteristics of leached cappings associated with a porphyry copper system. Coring confirmed the presence of an oxidized schist-quartz monzonite capping sequence with variable quartz-sericite, argillization, silicification, and traces of chalcocite. This altered leached capping block lay atop a low-angle fault with significant gouge, and the highly brecciated appearance of the block suggested that it was a slide block. Below the fault less brecciated to unbrecciated leached capping which graded into unbrecciated Pinal Schist cut by dikes of quartz monzonite was apparent. Both units below the fault were highly altered with development of quartz-sericite, argillization, and silicification. The rock contained up to 2 percent disseminated pyrite with chalcocite and bornite in quartz veins and alteration bands. Hole difficulties prompted a wedge hole (A-2W), which secured a second look at the low-grade copper mineralization and continued into the underlying sulfide zone. The wedge hole recovered 623 feet of core which averaged 0.30 percent copper and suggested a position near the expected target.

ASARCO continued drilling from 1973 to 1975. After securing a joint venture agreement with Inspiration Consolidated Copper Company, Hole AI-1 (fig. 5) was collared between hole A-2 and the eastern edge of the cover rocks. Brecciated Precambrian Pinal Schist with Tertiary granite was cored beneath the Whitetail Conglomerate. As with hole A-2, a basal flat fault with gouge was present at the base of the brecciated unit, here at a higher elevation. Unbrecciated basement schist with minor Tertiary aplite dikes continued to the termination of the hole. This bottom interval was weakly altered and contained sparse pyrite and trace copper as chalcopyrite similar to what was found in Inspiration's hole AOF-1 to the south, indicating the outer fringe of a porphyry copper system.

The data from hole AI-1 did not resolve the whereabouts of the Schultze Granite even though it was closer to where the granite disappeared under the cover rocks. Did the Schultze Granite terminate in the 4,200 feet from the hole to the nearest outcrop? N.P. Peterson (1963) mapped a fault along the contact of the Apache Leap Tuff with the Pinal Schist on the east side. D.W. Peterson (1969) mapped several faults along the eastern part of the plateau. Had a fault in this north-south system cut and displaced the nose? Was there strike-slip movement? Had the nose moved north or south? Were the distal alteration-mineralization at hole A-4 and the better grade intercept at hole A-2 on the north or south side of the porphyry system?

Hole DCA-3A (renamed; fig. 5, appendix 1) was drilled because the site was available, had previously been drilled to 2,980 feet where it ended in Whitetail Conglomerate, and offered a quick test to determine the direction of increased (or decreased) porphyry copper characteristics in pre-mineralized bedrock. This hole DCA-3A encountered two slide blocks within the Whitetail Conglomerate. The upper block consisted of Pinal Schist intruded by Laramide quartz monzonite, and the lower block consisted of quartz monzonite. Both blocks exhibited weak alteration and mineralization. Below the conglomerate a leached capping in Laramide quartz monzonite rested on a flat zone of fault gouge. Underlying the fault was Pinal Schist intruded by quartz monzonite. The low copper values of the lower block suggested the target was not on the north side of hole A-2.

Hole A-7 was collared north of hole A-4 to test the lower Whitetail Conglomerate basin. As in hole A-4, hole A-7 encountered three native copper mineralized zones totaling 375 feet of 0.85 percent copper in the Whitetail Conglomerate before bottoming in Permian Supai red beds.

Two state lease sections (Sections 4 & 5, T2S, R13E) had been acquired in 1973. Drill hole A-3 (fig. 5, appendix 1) was placed in one of these sections on the west side of Devils Canyon while drill hole A-6 (fig. 5) was placed in the other section on the east side of the canyon. Hole A-6 was terminated in Whitetail Conglomerate at 1,665 feet. It was later converted to a water well for the JI Ranch, and no further work was done in the hole.

Hole A-3 was rotary drilled before coring was begun and the hole rapidly reached 6,008 feet where it was terminated in Whitetail Conglomerate. A thin slide block of Precambrian diabase breccia was intersected near the bottom of the hole. Hole A-3 confirmed a deep basin on the west side of Devils Canyon. Although the total depth of -1,883 feet (below sea level) was 500 feet above where A-4 intersected bedrock to the north, the great depth and 4,578-foot thickness of the Whitetail Conglomerate were disheartening. Inspiration's hole AOF-1 (fig. 5, appendix 1) located 10,000 feet to the northeast on the east side of Devils Canyon intersected Pinal Schist bedrock at +1,292 feet elevation.

Logging of the Whitetail Conglomerate yielded clues to the deposition sequence in the basin. The conglomerate consists of cobble- to boulder-sized clast-supported debris with sand-sized matrix similar in composition to the clasts. Precambrian Pinal Schist and diabase are the dominant clast lithologies. Table 3 lists clast composition and percent matrix for the conglomerate by depth for hole A-3 from the depth of 2,400 feet to 6,008 feet. Clast composition is in essence a reverse stratigraphy of the region. At the base is abundant Paleozoic limestone debris shed from the uplands, whereas higher up or later in the depositional cycle erosion had cut down to Apache Group quartzites. The presence of Precambrian granite high in the hole attests to deep erosion of the source areas. Laramide intrusive debris is present between 4,700 and 5,000 feet in the hole. Mineralized fragments

Table 3. Percentage distribution of clast types and percent matrix by depth interval in drill hole A-3

Depth feet	PЄ Pinal Schist	PЄ Granite	Apache Group	Diabase	Paleozoics	Laramide	Matrix
			percent				
2400-2800	56	5	8	30	-	-	36
2800-3200	35	3	29	32	1	-	72
3200-4700	45	-	20	36	-	-	20
4700-5000	43	-	9	47	-	1	13
5000-5800	32	-	16	40	12	-	15
5800-5885	29	-	24	41	6	-	11
5885-5930	-	-	-	100	-	-	0*
5930-6008	31	-	8	58	2	1	8

* (Slide block of diabase)

ranging from oxidized porphyry to quartz veins in schist fragments were noted throughout.

Hole A-3 and other holes contained a number of volcanic tuff and fresh water limestone lenses. Two lenses of fine lithic biotite tuff were intersected at depths of 3,671 to 3,677 feet and 4,485 to 4,490 feet in hole A-3, suggesting that uplift, erosion, and basin-filling were repeated several times.

Additional information from holes DCA-1A, M-1A, A-7, A-4, and A-3 suggested a variably subsiding basin with a deeper central portion, pinchouts to the south, west, and north against basement units, and termination against the Devils Canyon Fault to the east. The resulting basin would have a half-moon shape and be filled with a wedge of sediment that would reach its greatest thickness against the Devils Canyon Fault.

Using various parameters, a model was established which indicated a possible plus 500 million tons of copper-bearing material in the basin with a 0.85 to 0.95 percent grade of copper as indicated by drill holes A-4 and A-7. The exploration target had been a bedrock deposit with a grade of up to 2 percent copper, but with the vast amount of copper suggested to be contained in a portion of the Whitetail Basin the question of whether the bedrock deposit had been eroded was raised. Erosion might have cut deeply into the deposit and left only a lower grade of 0.3 percent copper as in hole A-2.

Other than the United Verde and Howe Sound holes near the eastern edge of the volcanic plateau, only two of the thirteen holes started in Apache Leap Tuff (fig. 4) penetrated pre-mineralization basement (table 2). Magma's #6 shaft had also penetrated the cover rocks prior to ASARCO's entry into the area. The five penetrations by ASARCO (fig. 5) provided significant data on faulting, subsidence, alteration, and mineralization under the plateau. The extent of concealed Schultze Granite was still unknown, but slide blocks of quartz monzonite porphyry within the Whitetail Conglomerate indicated its presence. The existence of a deep basin between tilted outcrops of Naco Limestone to the west and outcrops of Pinal Schist to the east had been established. All Paleozoic and Precambrian sedimentary rocks east of the Devils Canyon Fault had been removed by erosion. Sediments at Superior are in excess of 5,000 feet thick and there is a 2,600 foot difference in elevation between the top of bedrock in holes A-2 and A-4, thus a minimum of 7,600 feet of down-to-the-west displacement occurred along the Devils Canyon Fault.

The discovery of porphyry copper type alteration and mineralization in holes A-2 and A-4, which are located over one and one half miles from each other, suggested the existence of a large porphyry copper system. The uplifted eastern block with its substantial thickness of low-grade copper mineralization was now a primary target beneath the volcanic plateau. Questions remained as to how much of the porphyry copper deposit had been eroded into the Whitetail Basin. Hypogene chalcocite-bornite was indicated in hole A-2, but it was doubtful if this would be sufficient for deep mining if no secondary enrichment was preserved.

The following geologic history was now clear: During post-Permian to pre-Whitetail time the area under the present volcanic plateau was displaced by several faults with one block preserving Permian red beds. During this interval oxidation was active, bedrock was tilted, the Schultze Granite and associated porphyries were emplaced, vein mineralization developed at Magma and elsewhere, and the north-south Devils Canyon Fault developed. These events are thought to be in response to development of a rift basin west of Superior (Hammer and Peterson, 1968). The Schultze Granite and porphyries were exposed and subjected to a major cycle of supergene enrichment and incipient gravity sliding as Whitetail Conglomerate deposition commenced.

Tectonic activity during Whitetail time offset the Whitetail Conglomerate, principally along the Devils Canyon Fault. Various slide blocks, some from the oxidized periphery of a porphyry copper system, were emplaced. The Whitetail Basin was filled and overflowed to the west through the gap near the Magma Vein, but the principal transport direction at Ray was south and southwest. A cycle of volcanism covered the beveled Whitetail Basin first with volcanic rocks to the north and later with the Apache Leap Tuff throughout.

DISCOVERY

ASARCO now had four holes (A-2, A-4, AI-1, and DCA-3A) which intersected variable degrees of alteration and mineralization in the pre-Tertiary bedrock units. Studies of sulfide-bearing bedrock, including alteration characteristics, sulfide type and distribution, type and distribution of dikes, fluid inclusions, copper-molybdenum ratios, lead-molybdenum ratios, and fault offsets, suggested that the core of the porphyry system lay to the south of hole A-2 (Sell, 1975).

Based on the amount and type of limonite in exotic blocks of leached-capping along with the occurrence and type of porphyry dikes and the amount of silicification, it was suggested that the blocks had to have been moved about 2,000 feet to roughly match up with the known bedrock data. Hole A-8 was therefore collared 1,800 feet southeast of hole A-2 (fig. 6, appen-

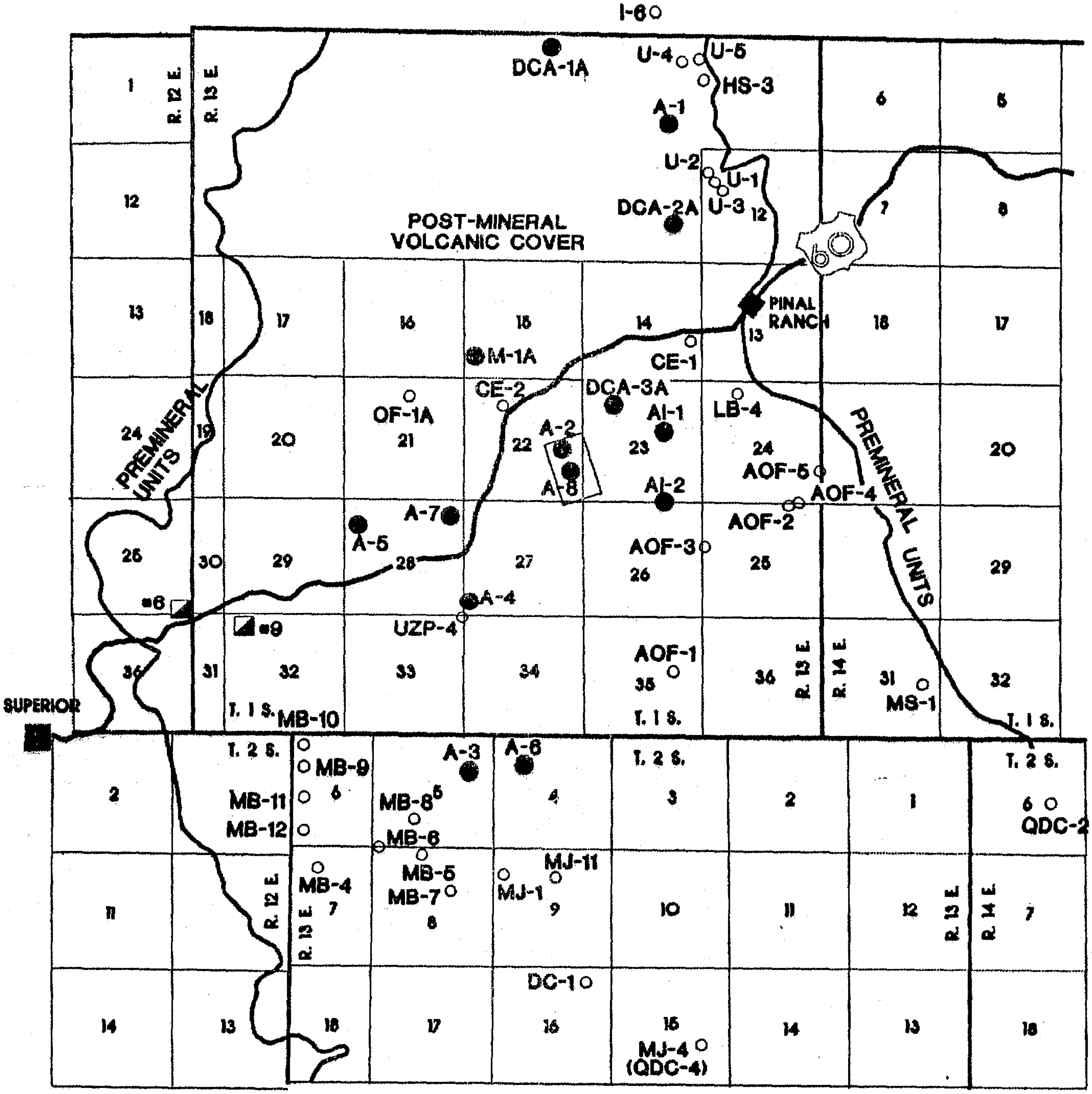


Figure 6. All holes drilled to date.

dix 1), and coring commenced. Drilling techniques and cost considerations had evolved so that a heavy-duty diamond core rig was considered the most economical means of securing a deep test. Hole A-8 was programmed for a depth of 5,000 to 5,500 feet.

The Apache Leap Tuff extended from the surface to 1,583 feet depth, earlier volcanic rocks to 2,213 feet, and the Whitetail Conglomerate to 3,226 feet. Below 3,226 feet a leached capping slide block was cored. Low copper values and moderate alteration were encountered in Pinal Schist with minor Laramide dikes down to a basal fault (thought to be the same as that found in holes A-2 and DCA-3A) at 3,774 to 3,777 feet. Below the fault an additional 102 feet of oxidized Pinal Schist with remnant chalcocite in quartz sericite veins was cored.

The sulfide zone from 3,879 to 4,525 feet contained quartz veins and disseminations of hypogene chalcocite and bornite in argillic and quartz-sericite altered Pinal Schist with Laramide biotite feldspar porphyry dikes. Very little pyrite is present in this 646-foot section of mineralized rock, which averaged 1.57 percent copper. From 4,525 to 4,660 feet the grade dropped to 0.26 percent copper with minor pyrite and chalcopyrite, and grade continued to decrease to the bottom of the hole at 4,907 feet. Potassium feldspar and quartz veins in the lower part of the hole suggested that the core of the porphyry copper system had been penetrated.

ASARCO POST-DISCOVERY EXPLORATION

ASARCO went on to drill holes A-9 through A-16 in an area 3,000 feet long and 2,500 feet wide to the southeast of hole A-2. Additionally, hole AI-2 was drilled 2,700 feet south of AI-1 on ASARCO-Inspiration joint venture ground (fig. 6, appendix 1). Low copper values in hole AI-2 suggests that higher grade mineralization does not extend that far.

The central porphyry mass has not been delineated to date. Kreis (1986) described the various igneous dikes within the drilled areas and surrounding outcrops. Granodiorite, granodiorite porphyry, quartz monzonite, quartz monzonite porphyry, quartz feldspar porphyry, and fine-grained granite constitute the igneous suite from oldest to youngest. The granodiorite and granodiorite porphyry may be Schultze Granite occurring deep in hole A-4 and at the bottom of hole A-12. The quartz feldspar porphyry is in the central holes A-8, A-9, and A-10.

The mineralized system is only partially defined with the holes drilled to date. One interpretation based on present copper intercepts is that a northeasterly elongated elliptical mineralized system has been more than half eroded or faulted away. At least three major northeast-trending faults with northwest sides displaced downward cut the area.

OTHER DRILLING

Other companies had been active prior to the entry of ASARCO in the district, and Magma, Kennecott, and the DOE continued during the ASARCO interval. All the known holes collared on the volcanic surface of the Apache Leap Plateau are plotted on figure 6, and appendix 1 tabulates data from all these holes.

SUMMARY AND CONCLUSIONS

Discovery of a porphyry copper deposit with a hypogene grade of plus 1 percent copper off the southwestern nose of the Schultze Granite was an explorationist's dream come true. Looking back, those years were an excellent time for a geologist because ASARCO encouraged new ideas, funded the testing of those ideas, was persistent, and looked to the future. Also the upgrade of drilling technology and skill was without parallel during that time.

Prior to ASARCO's entry into drilling on the plateau, 23 holes totaling 33,830 feet had been completed by other companies. Only 3 of those holes totaling 8,947 feet reached bedrock, the remaining footage was unproductive due to equipment limits and lack of persistence and funding. In contrast to this early work, ASARCO drilled a total of 89,818 feet in 23 holes of which only three totaling 10,818 feet did not reach bedrock.

The ultimate size and grade within the system has yet to be determined. A preliminary view is that the system will be large and ring-like like Ray (Phillips and others, 1974). Only part of the ring has been drilled to date.

ACKNOWLEDGMENTS

I thank the succession of Tucson exploration managers, New York chief geologists and vice-presidents, and ASARCO corporate managers who contributed their thoughts and support from the project's start in 1970. Geologists from ASARCO and other organizations also contributed to the success of the project, as did the drillers who completed the holes which provided the information that guided exploration and ultimate discovery.

Thanks are given especially to Dr. D.W. Peterson of the U.S. Geological Survey for words of wisdom on the Apache Leap Tuff. Dr. D.W. Peterson contributed the cover rocks section to this paper. Finally, special thanks are given to ASARCO Incorporated and other companies for permission to publish the data in this paper.

References follow Appendixes

APPENDIX 1. Drill data of rotary (R) and core (C) holes, with the kick-off points (KOP) and total depths (T.D.) (all units in feet)

Company/ Hole #	Drilling Dates	Collar Elevation	Alluvium /Gila	Dacite	Apache Leap Tuff Vitrophyre	Tuff
<u>Arizona Mining</u>						
LB-4 NW¼NE¼NW¼ Sec. 24 T1S, R13E	R Nov. 24-Dec. 24, 1973 (0-2344) C Jan.28-July 30, 1974 (2344-4860) T.D.	4700	—	0-265(265)	265-297(32)	297-320(23)
<u>ASARCO</u>						
A-1 SE¼NW¼SE¼ Sec. 2 T1S, R13E	R April 8-27, 1971 (0-1309) C July 14-Aug. 12, 1971 (1309-2129) T.D.	4720	—	0-1250(1250)	1250-1297(47)	1297-1374 (77)
A-2 NE¼NE¼SE¼ Sec. 22 T1S, R13E	R Jan. 12-Feb. 8, 1972 (0-4078) C Feb. 21-March 17, 1972 (4078-4521) T.D.	4303	—	0-1225(1225)	1225-1235(10)	1235-1330(95)
A-2W (Wedge hole from A-2)	C April 18-May 18, 1972 (4230-4940) T.D.	KOP 73	—	—	—	—
A-3 NW¼SE¼NE¼ Sec. 5 T2S, R13E	R May 22-June 4, 1973 (0-1445) R May 10-May 19, 1974 (1445-1949) C Sept. 26-Dec. 1, 1975 (1949-6008) T.D.	4125	—	0-1375(1375)	1375-1410(35)	1410-1430(20)
A-4 NW¼SW¼SW¼ Sec. 27 T1S, R13E	R May 1-25, 1971 (0-2077) R June 12-July 21, 1971 (2077-3593) C Aug. 16-Nov. 4, 1971 (3593-6664) T.D.	4100	—	0-1770(1770)	1770-1798(28)	1798-1975(177)
A-5 SW¼NW¼NW¼ Sec. 28 T1S, R13E	R July 28-Aug. 28, 1971 (0-3145) T.D.	4020	—	0-2106(2106)	2106-2167(61)	2167-2274(107)
A-6 SE¼NW¼NW¼ Sec. 4 T2S, R13E	R June 6-16, 1973 (0-1358) R May 20-29, 1974 (1358-1665)T.D.	4120	—	0-1415(1415)	1415-1455(40)	1455-1475(20)
A-7 SW¼NE¼NE¼ Sec. 28 T1S, R13E	R Aug. 20-Sept.14, 1973 (0-3150) C Nov. 27, 1973-Feb. 9, 1974 (3150-6042) T.D.	4215	—	0-1990(1990)	1990-2005(15)	2005-2100(95)
A-8 NW¼SW¼SW Sec. 23 T1S, R13E	C Aug. 5-Dec. 28, 1976 (0-4907) T.D.	4671	—	0-1505(1505)	1505-1536(31)	1536-1583(47)
A-9 SE¼NW¼SW¼ Sec. 23 T1S, R13E	C Jan 7-May 3, 1977 (0-4903) T.D.	4627	—	0-1386(1386)	1386-1435(49)	1435-1478(43)
A-10 NW¼SE¼SE¼ Sec. 22 T1S, R13E	C May 6-Dec. 27, 1977 (0-4282) T.D.	4585	—	0-1468(1468)	1468-1492(24)	1492-1599(107)
A-11 SW¼NW¼SW¼ Sec. 23 T1S, R13E	C Aug. 2-Nov. 22, 1978 (0-4940) Wedge -June 1979 (4924-5175) T.D.	4608	—	0-1362(1362)	1362-1437(75)	1437-1458(21)
A-12 (Wedge hole from A-11)	Dyni-drill Jan. 14-March 5, 1980 (2750-2879) Navi-drill March 12-June 1, 1981 (2879-4217) C June 2-Nov. 10, 1981 (4217-5724) T.D.	KOP 1858	—	KOP in Tw		
A-12A (Wedge hole from A-12)	C Nov. 11-Dec. 19, 1981 (4093-4240) T.D.	KOP 515	—	KOP in P€pl		

APPENDIX 1. Continued

Company/Hole #	Earlier Volcanics	Whitetail Conglomerate	(Tw)	Bedrock Units (see explanation of units)
Arizona Mining				
LB-4 NW¼NE¼NW¼ Sec. 24 T1S, R13E	320-334(14)	None		Tgr 334-4860(4526) T.D.
ASARCO				
A-1 SE¼NW¼SE¼ Sec. 2 T1S, R13E	None	P€piBxSB 1374-1527 Tw 1527-1566 Tw	(153) (39) 192	P€piBx & fault 1566-1588(22), P€pi 1588-2129 (541) T.D.
A-2 NE¼NE¼SE¼ Sec. 22 T1S, R13E	1330-2020(690)	Tw 2020-3459 TqmpSB 3459-3540 Tw 3540-3920 Tw	(1439) (81) (380) 1900	TqmpSB 3920-4079(159), P€pl w/dikes SB & b flt 4079-4295(216), P€pl 4295-4513 (218) T.D.
A-2W (Wedge hole from A-2)	—	—		Wedge hole from A-2: P€piSB & b flt 4230-4295(65), P€pi-Tqm 4295-4940 (645) T.D.
A-3 NW¼SE¼NE¼ Sec. 5 T2S, R13E	None	Tw 1430-5885 P€dbSB 5885-5930 Tw 5930-6008 Tw	(4455) (45) (78) T.D. 4578	Not reached
A-4 NW¼SW¼SW¼ Sec. 27 T1S, R13E	1975-2133(158)	Tw 2133-6336 MeBxSB 6336-6448 Tw 6448-6484 Tw	(4203) (112) (36) 4351	Me & flt 6484-6575(91), Tqm-P€pl 6575-6664(89) T.D.
A-5 SW¼NW¼NW¼ Sec. 28 T1S, R13E	2274-2600(326)	2600-3145	(545) T.D.	Not reached
A-6 SE¼NW¼NW¼ Sec. 4 T1S, R13E	None	1475-1665	(190) T.D.	Not reached
A-7 SW¼NE¼NE¼ Sec. 28 T1S, R13E	2100-2445(345)	Tw 2445-3682 TgrSB 3682-3730 Tw 3730-5610 Tw	(1237) (48) (1880) 3165	Psupal 5610-5810(200), Pnaco 5810-6042(232) T.D.
A-8 NW¼SW¼SW¼ Sec. 23 T1S, R13E	1583-2213(630)	2213-3226	(1013)	P€pi-TgrSB & b flt 3226-3777(551), P€pi-Tbfp 3777-4907 (1130) T.D.
A-9 SE¼NW¼SW¼ SEC. 23 T1S, R13E	1478-2194(716)	2194-3275	(1081)	P€pi-TqmBxSB & b flt 3275-3693(418), P€pi-Tqmp 3693-4903 (1210) T.D.
A-10 NE¼SE¼SE¼ Sec. 22 T1S, R13E	1599-2138(539)	2138-3375	(1237)	P€pi-TqfpBxSB & b flt 3375-3859(484), P€pi-Tqfp 3859-4282(423) T.D.
A-11 SW¼NW¼SW¼ Sec. 23 T1S, R13E	1458-2215(757)	2215-3492	(1277)	P€pi-TqfpBxSB & b flt 3492-4085(593), P€pi-Tqfp 4085-5175(1090) T.D.
A-12 (Wedge hole from A-11)	KOP in Tw	2750-3500	(750)	P€pi-TqfpBxSB & flt 3500-4070(570), P€pi-Tqfp 4070-5724(1654) T.D.
A-12A (Wedge hole from A-12)	KOP in P€pl	KOP in P€pl		P€pi-Tqfp 4093-4240(147) T.D.

APPENDIX 1. Drill data of rotary (R) and core (C) holes, with the kick-off points (KOP) and total depths (T.D.) (all units in feet)

Company/ Hole #	Drilling Dates	Collar Elevation	Alluvium /Gila	Dacite	Apache Leap Tuff	
					Vitrophyre	Tuff
A-13 SE¼SW¼SW¼ Sec. 23 T1S, R13E	C March 6-Sept. 17, 1980 (0-4663) T.D.	4728	—	0-1562(1562)	1562-1565(3)	1565-1580(15)
A-14 SE¼NE¼SE¼ Sec. 22 T1S, R13E	R June 17-July 2, 1980 (0-1534) C Sept. 18, 1980-March 12, 1981 (1534-5738) T.D.	4694	—	0-1554(1554)	1554-1595(41)	1595-1652(57)
A-15 NE¼SW¼SW¼ Sec. 23 T1S, R13E	C Feb. 16-April 6, 1983 (0-2029) C April 2-June 6, 1984 (2029-4699) T.D.	4628	—	0-1437(1437)	1437-1502(65)	1502-1512(10)
A-16 SW¼SW¼SW¼ Sec. 23 T1S, R13E	R June 23-July 16, 1987 (0-1020) C June 14-23, 1988 (1020-1380) C Aug. 21-Sept. 20, 1989 (1380-2446) C Nov. 1, 1990-March 28, 1991 (2446-5212) T.D.	4781	—	0-1614(1614)	1614-1648(34)	1648-1692(44)
A-17 NE¼NW¼SW¼ Sec. 23 T1S, R13E	C Aug. 9-23, 1992 (0-820) T.D.	4811	—	0-820(820) T.D.	Not reached	Not reached
AI-1 SE¼SW¼NE¼ Sec. 23 T1S, R13E	R July 18-Aug. 12, 1973 (0-2768) C Oct. 1-Nov. 21, 1973 (2768-3967) T.D.	4620	—	0-1495(1495)	1495-1510(15)	1510-1565(55)
AI-2 SE¼SW¼SE¼ Sec. 23 T1S, R13E	C March 28-Aug. 18, 1980 (0-3612) T.D.	4715	—	0-1439(1439)	1439-1444(5)	1444-1472(28)
Can-US Ltd.						
MJ-1 SW¼NW¼NW¼ Sec. 9 T2S, R13E	R Nov.-Dec. 1972 (0-2370) C Dec. 1972-Feb. 1973 (2370-3304) T.D.	3960	—	0-1010(1010)	Included	Included
MJ-1 (re-entered by Magma)	C Nov '75-Jan. '76 (3304-4426) T.D.	KOP 656	—	—	—	—
MJ-4 SE¼NE¼SE¼ Sec. 15 T2S, R13E	R (0-1245) T.D	3510	—	0-1230(1230)	Included	Included
MJ-11 SE¼NW¼NE¼ Sec. 9 T2S, R13E	R (0-805) T.D.	3900	—	0-805(805) T.D.	Not reached	Not reached
Cibola Exploration						
CE-1 NE¼NW¼SE¼ Sec. 14 T1S, R13E	Churn Drill 1930's(?) (0-2850) T.D.	4485	—	0-2200(2200)	Included	Included
CE-2 SW¼NE¼NW¼ Sec. 22 T1S, R13E	Churn Drill 1930's(?) (0-1490) T.D.	4080	—	0-1490(1490) T.D.	Not completed thru T.D.(?).	
Continental Materials						
M-1 NW¼SW¼SW¼ Sec. 15 T1S, R13E	R Sept.-Oct. 1970 (0-2402) T.D.	4550	—	0-1570(1570)	1570-1596(26) 1802-1830(28)	1596-1802(206) 1830-1890(60)
M-1A (reentered M-1)	C April 20-July 3, 1971 (2402-5322) T.D.		Deepened by Asarco	—	—	—
M-W SW¼NE¼NE¼ Sec. 21 T1S, R13E	R Sept. 1970 (0-200) T.D.	4280	—	0-200(200) T.D.	Not reached	Not reached

APPENDIX 1. Continued

Company/Hole #	Earlier Volcanics	Whitetail Conglomerate	(Tw)	Bedrock Units (see explanation of units)
A-13 SE¼SW¼SW¼ Sec. 23 T1S, R13E	1580-2036(456)	2036-3071	(1035)	P€piBxSB & b flt 3071-3260(189), P€pi-Tqm 3260-4663(1403) T.D.
A-14 SE¼NE¼SE¼ Sec. 22 T1S, R13E	1652-2289(637)	2289-3841	(1552)	P€piBxSB & b flt 3841-4015(174), P€pi-Tap.-Tqfp 4015-5738(1723) T.D.
A-15 NE¼SW¼SW¼ Sec. 23 T1S, R13E	1512-2069(557)	2069-2905	(836)	P€piBxSB & b flt 2905-3338(433), P€pi 3338-4699(1361) T.D.
A-16 SW¼SW¼SW¼ Sec. 23 T1S, R13E	1692-2231(539)	2231-3010	(779)	P€piBxSB & b flt 3010-3121(111), P€pi-Tqfp 3121-5212(2091) T.D.
A-17 NE¼NW¼SW¼ Sec. 23 T1S, R13E	Not reached	Not reached		Not reached
AI-1 SE¼SW¼NE¼ Sec. 23 T1S, R13E	1565-2250(685)	2250-2800	(550)	P€pi-Tgr BxSB & b flt 2800-3262(462), P€pi w/minor Tap.dikes 3262-3967(705) T.D.
AI-2 SE¼SW¼SE¼ Sec. 23 T1S, R13E	1472-1780(308)	1780-2616	(836)	P€pi 2616-3612(996) T.D.
<u>Can-US Ltd.</u>				
MJ-1 SW¼NW¼NW¼ Sec. 9 T2S, R13E	None	Tw 1010-2919	(1909)	Pnaco 2919-3304(385) T.D.
MJ-1 (re-entered by Magma)	—	—		Pnaco 3304-3674(370) [755 Total], Mc 3674-4141(467), Dm 4141-4426(285) T.D.
MJ-4 SE¼NE¼SE¼ Sec. 15 T2S, R13E	None	1230-1245	(15) T.D.	Not reached
MJ-11 SE¼NW¼NE¼ Sec. 9 T2S, R13E	Not reached	Not reached		Not reached
<u>Cibola Exploration</u>				
CE-1 NE¼NW¼SE¼ Sec. 14 T1S, R13E	2200-2850(650) T.D.	Not completed thru Tev.		Not reached
CE-2 SW¼NE¼NW¼ Sec. 22 T1S, R13E	Not reached	Not reached		Not reached
<u>Continental Materials</u>				
M-1 NE¼SW¼SW¼ Sec. 15 T1S, R13E	1890-2402(512) T.D.	Not completed thru Tev.		Not reached
M-1A (reentered M-1)	2402-2428 <u>(26)</u> Tev 538	Tw 2428-2920 TqmSB 2920-3108 Tw 3108-4898 Tw	(492) (188) <u>(1790)</u> 2470	PSupai 4898-5108(210), Pnaco 5108-5322(214) T.D.
M-W SW¼NE¼NE¼ Sec. 21 T1S, R13E	Not reached	Not reached		Not reached

APPENDIX 1. Drill data of rotary (R) and core (C) holes, with the kick-off points (KOP) and total depths (T.D.) (all units in feet)

Company/ Hole #	Drilling Dates	Collar Elevation	Alluvium /Gila	Dacite	Apache Leap Tuff Vitrophyre	Tuff
DOE						
USW UZP-4 NW¼SE¼SE¼ Sec. 28 T1S, R13E	R-C March-June 1990 (0-1713) T.D.	4076	—	0-1713(1713) T.D.	Not reached	Not reached
USW UZP-5 (8'NE of UZP-4)	C June 1990 (0-233) T.D	4076	—	0-233(233) T.D.	Not reached	Not reached
Howe Sound						
HS-3 NW¼SE¼NE¼ Sec. 2 T1S, R13E	R April-May 1956 (0-325) T.D.	4170	—	0-42(42)	42-46(4)	None
Inspiration						
AOF-1 SW¼SE¼NE¼ Sec. 35 T1S, R13E	C April-Oct. 1964(0-3475) T.D.	4230	—	0-1045(1045)	1045-1060(15)	1060-1106(46)
AOF-2 SE¼SW¼SE¼ Sec. 24 T1S, R13E	R Aug. 1966 (0-1581) C Aug. 1966-April 1967 (1581-3085) T.D.	4975	—	0-780(780)	Included	Included
AOF-3 NW¼SW¼NW¼ Sec. 25 T1S, R13E	R (0-122) T.D.	4520	—	0-122(122) T.D.	Not reached	Not reached
AOF-4 SW¼SE¼SE¼ Sec. 24 T1S, R13E	R August 1969 (0-864) T.D.	5000	—	0-864(864) T.D.	Included	Included
AOF-5 SE¼NE¼SE¼ Sec. 24 T1S, R13E	R Aug.-Nov. 23, 1970(0-1755) T.D.	5100	—	0-1030(1030)	Included	Included
I-6 NW¼SW¼SW¼y Sec. 34 T1N, R13E	C fall, 1970. Inclined-55° @ N36°W (0-2000) T.D. (±1650' vertical)	3840	—	0-2000(at-55°) T.D. (±1650' vertical) T.D.	?	?
Kennecott						
MS-1 NW¼SW¼NE¼ Sec. 31 T1S, R14E	R Oct. 1991 (0-1270) T.D.	4170	—	0-1270(1270) T.D.	Not reached	Not reached
Kerr-McGee						
OF-1 NW¼NW¼NE¼ Sec. 21 T1S, R13E	R Sept. 17-24, 1964 (0-671) T.D.	4410	—	0-671(671) T.D.	Not reached	Not reached
OF-1A (8'N offset of OF-1)	R Oct. 27-Nov. 4, 1964 (0-2150) T.D.	4410	—	0-1635(1635) 1670-1790(120) 1840-1875(35)	1635-1670(35) 1790-1840(50) 1875-1930(55)	1930-1995(65)
DC-1 NW¼NE¼NE¼ Sec. 16 T2S, R13E	R Nov. 27-Dec. 17, 1964 (0-2303) T.D.	3990	—	0-1130(1130)	1130-1160(30)	1160-1165(5)
DC-1 Reentered & Deepened by Magma	C Feb-April 1974 (2303-4200) T.D.	KOP 1687	—	—	—	—
Magma						
#6 Shaft SE¼SE¼SE¼ Sec. 25 T1S, R12E	*1928, deepened 1957* (0-3700) T.D.	*3659*	—	*0-670(670)*	*Included*	*Included*
#9 Shaft NE¼NW¼NW¼ Sec. 32 T1S, R12E	1969-1973 (0-4750) T.D.	4190	—	0-1875(1875)	Included	Included

APPENDIX 1. Continued

Company/Hole #	Earlier Volcanics	Whitetail Conglomerate (Tw)	Bedrock Units (see explanation of units)
DOE			
USW UZP-4 NW¼SE¼SE¼ Sec. 28 T1S, R13E	Not reached	Not reached	Not reached
USW UZP-5 (8'NE of UZP-4	Not reached	Not reached	Not reached
Howe Sound			
HS-3 NW¼SE¼NE¼ Sec. 2 T1S, R13E	None	None	PЄpi 46-325(279) T.D.
Inspiration			
AOF-1 SW¼SE¼NE¼ Sec. 35 T1S, R13E	None	1106-2939 (1833)	PЄdb 2939-3040(101), PЄpi 3040-3054(14), PЄdb 3054-3237(183), PЄpi 3237-3475(238) T.D.
AOF-2 SE¼SW¼SE¼ Sec. 24 T1S, R13E	None	780-3058 (2278) T.D.	Not reached
AOF-3 NW¼SW¼NW¼ Sec. 25 T1S, R13E	Not reached	Not reached	Not reached
AOF-4 SW¼SE¼SE¼ Sec. 24 T1S, R13E	Not reached	Not reached	Not reached
AOF-5 SE¼NE¼SE¼ Sec. 24 T1S, R13E	None	1030-1755 (725) T.D.	Not reached
I-6 NW¼SW¼SW¼ Sec. 34 T1N, R13E	Not reached	Not reached	Not reached
Kennecott			
MS-1 NW¼SW¼NE¼ Sec. 31 T1S, R14E	Not reached	Not reached	Not reached
Kerr-McGee			
OF-1 NW¼NW¼NE¼ Sec. 21 T1S, R13E	Not reached	Not reached	Not reached
OF-1A (8'N offset of OF-1)	1995-2150(155) T.D.	Not reached	Not reached
DC-1 NW¼NE¼NE¼ Sec. 16 T2S, R13E	None	1165-2303 (1138) T.D.	Not Reached
DC-1 Reentered & Deepened by Magma		Magma reentered in Tw: 2303-3665 (1362) T.D. Tw 2500	Pnaco 3665-4200(535) T.D.
Magma			
#6 Shaft SE¼SE¼SE¼ Sec. 25 T1S, R12E	None	670-1250 (580)	Pnaco 1250-2350(1100), Me 2350-2800(450), Dm 2800-3300(500), PЄt 3300-3500(200), PЄdb 3500-3700(200) T.D.
#9 Shaft NE¼NW¼NW¼ Sec. 32 T1S, R12E	None	1875-3250 (1375)	Tbx 3250-4750(1500) T.D.

APPENDIX 1. Drill data of rotary (R) and core (C) holes, with the kick-off points (KOP) and total depths (T.D.) (all units in feet)

Company/ Hole #	Drilling Dates	Collar Elevation	Alluvium /Gila	Dacite	Apache Leap Tuff Vitrophyre	Tuff
#9 Shaft Vertical Diamond Drill Hole	*1975* (4750-6750) T.D.	KOP -560	—	—	—	—
MB-4 NE¼NW¼NW¼ Sec. 7 T2S, R12E	C Nov. 1973, Jan. 1974 (0-3224) T.D.	4330	—	0-1060(1060)	Included	Included
MB-5 NE¼NE¼NW¼ Sec. 8 T2S, R13E	R April 1974 (0-1791) C April-July 1974 (1791-3655) T.D.	4160	—	0-920(920)	Included	Included
MB-6 SE¼SE¼SE¼ Sec. 6 T2S, R13E	R July 1975 (0-1803) C Aug.-Dec. 1975 (1803-3668) T.D.	4020	—	0-800(800)	Included	Included
MB-7 NW¼SW¼NE¼ Sec. 8 T2S, R13E	C Sept. 1975-Jan. 1976 (0-1460)	3870	0-15(15)	15-630(615)	630-655(25)	Included
	C Sept. 1977 (1460-3890) T.D.	—	—	—	—	—
MB-8 NE¼SW¼SW¼ Sec. 8 T2S, R13E	1976 ? C 0-3924 T.D.	4100	—	0-1000	Included	Included
MB-9 SE¼NW¼NW¼ Sec. 6 T2S, R13E	R Sept.-Oct. 1991 (0-2115) C Nov. 1991-Jan. 1992 (2115-3267) T.D.	4122	—	0-1168(1168)	1168-1230(62)	1230-1253(23)
MB-10 NE¼NW¼NW¼ Sec. 6 T2S, R13E	R Oct.-Nov. 1991 (0-2118) T.D.	4031	—	0-1170(1170)	1170-1225(55)	1225-1230(5)
MB-11 NE¼NW¼SW¼ Sec. 6 T2S, R13E	C Jan.-March 1992 (0-3367) T.D.	4080	—	0-996(996)	996-1041(45)	1041-1068(27)
MB-11A (Same pad as MB-11) Inclined-80° due South	C Dec. 1992-April 1993 (0-4667) T.D.	4080	—	0-980(980)	980-990(10)	990-1017(27)
MB-11B Wedge at 2792 in Tbx from MB-11A	C April-June 1993 (2792-4349) T.D.	KOP 1288	—	KOP in Tbx	—	—
MB-12 SE¼NW¼SW¼ Sec. 6 T2S, R13E	C April-July 1992 (0-4008) T.D.	4106	—	0-967(967)	967-1041(74)	1041-1053(12)
MB-12A Same location as MB-12 Inclined-80°, 55°W	C June-Sept. 1993 (0-3527) T.D.	4106	—	0-947(947)	947-1007(60)	1007-1014(7)
Quintana						
QDC-2 NW¼NE¼SW¼ Sec. 7 T2S, R14E	R July 1976 (0-577) C July-Sept. 1976 (577-2739) T.D.	3275	0-1030(1030)	1030-1884(854)	1884-1902(18)	None
QDC-4 Can-US hole MJ-4 renamed and reentered by Quintana SE¼NE¼SE¼ Sec. 15 T2S, R13E	C Aug.-Dec., 1976 (1245-3997) T.D.	KOP 2265	—	—	—	—

APPENDIX 1. Continued

Company/Hole #	Earlier Volcanics	Whitetail Conglomerate	(Tw)	Bedrock Units (see explanation of units)
#9 Shaft Vertical Diamond Drill Hole	—	—		Tbx 4750-6750 (2000) T.D. Tbx 3500
MB-4 NE¼NW¼NW¼ Sec. 7 T2S, R12E	None	1060-1745	(685)	Pnaco 1745-2302(557), (flt-vn) Me 2302-2437(135), Dm 2437-2787(350), Єb 2787-3051(264) (flt), PЄdb 3051-3224(173) T.D.
MB-5 NE¼NE¼NW¼ Sec. 8 T2S, R13E	None	920-2537	(1617)	Pnaco 2537-2775(238), porphyry 2775-2796(21) Pnaco 2796-3235(439), Me 3235-3438(203), Dm 3438-3655(217) T.D.
MB-6 SE¼SE¼SE¼ Sec. 6 T2S, R13E	None	800-2209	(1409)	Pnaco 2209-2838(629), Me 2838-3217(379), Dm 3217-3556(339), Єb 3556-3668(112) T.D.
MB-7 NW¼SW¼NE¼ Sec. 8 T2S, R13E	None	655-1430	(775) T.D.	Not reached
		reentered in Tw: 1430-3050	(1620) Tw 2395	Pnaco 3050-3090(40), Me 3090-3255(165), Dm 3255-3890(635) T.D.
MB-8 NE¼SW¼SW¼ Sec. 8 T2S, R13E	None	1000-2640	(1640)	Pnaco 2640-3365(725), Me 3365-3510(145), Dm 3510-3820(310), porphyry 3820-3850(30), Dm 3850-3900(50), Єb 3900-2924(24) T.D.
MB-9 SE¼NW¼NW¼ Sec. 6 T2S, R13E	None	1253-2655	(1402)	Tbx 2655-3267(612) T.D.
MB-10 NE¼NW¼NW¼ Sec. 6 T2S, R13E	None	1230-2118	(888)	Not reached
MB-11 NE¼NW¼SW¼ Sec 6 T2S, R13E	None	1068-1450	(382)	Tbx 1450-3367(1917) T.D.
MB-11A (Same pad as MB-11) Inclined-80° due South	None	1017-1459	(442)	Tbx 1459-4667(3208) T.D.
MB-11B Wedge at 2792 in Tbx from MB-11A	None	KOP in Tbx		Tbx 2792-3448(656), Єb 3448-3528(80) Tbx 3528-4220(692), PЄdb 4220-4349(129) T.D.
MB-12 SE¼NW¼SW¼ Sec. 6 T2S, R13E	None	1053-1342	(289)	Tbx-seds 1342-2712(1370), Pnaco-Tbx 2712-3356 (644), Me-Tbx 3356-3510(154), Tbx 3510-3842(332), PЄdb 3842-4008(166) T.D.
MB-12A Same location as MB-12 Inclines-80°, 55°W	None	1014-1300	(286)	Tbx1300-1816(516), Pnaco 1816-2489(673), Me 2489-2751(262), Dm 2751-2851(100), Єb 2851-3181(330),PЄdb 3181-3527(346) T.D.
<u>Quintana</u>				
QDC-2 NW¼NE¼SW¼ Sec 7 T2S, R14E	None	1902-2622	(720)	PЄdb BxSB & b flt 2622-2640(18), PЄpl 2640-2739(99) T.D.
QDC-4 Can-US hole MJ-4 renamed and reentered by Quintana SE¼NE¼SE¼ Sec. 15 T2S, R13E	—	Reentered in Tw: 1245-3997	(2752) T.D. Tw 2767	Not reached

APPENDIX 1. Drill data of rotary (R) and core (C) holes, with the kick-off points (KOP) and total depths (T.D.) (all units in feet)

Company/ Hole #	Drilling Dates	Collar Elevation	Alluvium /Gila	Dacite	Apache Leap Tuff Vitrophyre	Tuff
Superior Oil-Miami Copper						
DCA-1 NE¼NW¼NW¼ Sec. 3 T1S, R13E	R May 18-June 26, 1964 (0-4011) T.D.	4760	—	0-1310(1310)	1310-1420(50)	1360-1420(60)
DCA-1A Reentered & Deepened by Asarco	C Nov. 17, 1971-Feb. 9, 1972 (4011-5813) T.D.	KOP 749	—	—	—	—
DCA-2 SE¼NW¼SE¼ Sec. 11 T1S, R13E	R July 3-12, 1964, (0-1471) R June 27-July 24, 1965 (1471-1772) T.D.	4720	—	0-1095(1095)	1095-1125(30)	1125-1340(215)
DCA-2A Reentered & Deepened by Asarco	C Oct. 25-Dec. 18, 1974 (1352-2422) T.D.	KOP 3368	—	—	—	—
DCA-3 SW¼NE¼NW¼ Sec. 23 T1S, R13E	R May 7-June 21, 1965 (0-2980) T.D.	4625	—	0-1400(1400)	1400-1415(15)	1415-1490(75)
DCA-3A Reentered & Deepened by Asarco	C July 1-Oct. 21, 1974 (2980-5154) T.D.	KOP 1645	—	—	—	—
Unknown						
C-1 SE¼NE¼SE¼ Sec. 14 T1S, R13E	R (0-500) T.D.	4480	0-200(200)	200-500(300) T.D.	Included	Included
C-2 NE¼NE¼SE¼ Sec. 14 T1S, R13E	R (0-1027) T.D.	4480	—	0-1027(1027) T.D.	Included	Included
United Verde						
U-1 SW¼NW¼NW¼ Sec. 12 T1S, R13E	C Oct. 1-28, 1930 (0-780) T.D.	5024	—	0-711(711)	Included	Included
U-2 SW¼NW¼NW¼ Sec. 12 T1S, R13E	C Jan. 21-March 26, 1931 (0-1146) T.D.	4922	—	0-680(680)	680-710(30)	710-737(27)
U-3 NW¼SW¼NW¼ Sec. 12 T1S, R13E	C Jan. 29-March 2, 1931 (0-875) T.D.	5029	—	0-618(618)	618-620(2)	620-625(5)
U-4 SW¼NE¼NE¼ Sec. 2 T1S, R13E	C Jan. 20-May 22, 1931 (0-1600) T.D.	4721	—	0-1170(1170)	1170-1215(45)	1215-1235(20)
U-5 SE¼NE¼NE¼ Sec. 2 T1S, R13E	C April 6-May 20, 1931 (0-835) T.D.	4379	—	0-418(418)	418-435(17)	435-488(53)

APPENDIX 1. Continued

Company/Hole #	Earlier Volcanics	Whitetail Conglomerate	(Tw)	Bedrock Units (see explanation of units)
Superior Oil-Miami Copper				
DCA-1 NE¼NW¼NW¼ Sec. 3 T1S, R13E	1420-2210(790)	2210-4011	(1801) T.D.	Not reached
DCA-1A Reentered & Deepened by Asarco		Reentered, started in Tw: 4011-4669 Tw	 (658) 2459	Pnaco 4669-4998(329), Me 4998-5452(454), Dm 5452-5768(316), P€t 5768-5813(45) T.D.
DCA-2 SE¼NW¼SE¼ Sec. 11 T1S, R13E	None	1340-1525	(185)	P€pi 1525-1575(50), Tqm 1575-1678(103), P€pi 1678-1772(94) T.D.
DCA-2A Reentered & Deepened by Asarco		Reentered, started in Tw: 1352-1452	 (100)	P€pi-Tqm 1452-1827(375), P€pi 1827-2422(595) T.D.
DCA-3 SW¼NE¼NW¼ Sec. 23 T1S, R13E	1490-2430(940)	2430-2980	(550) T.D.	Not reached
DCA-3A Reentered & Deepened by Asarco		Reentered, started in Tw: 2980-4081 P€pi-*TqmBxSB* 4081-4159 Tw 4159-4297 TqmBxSB 4297-4394 Tw 4394-4454 Tw	 (1101) (78) (138) (97) (60) 2024	TqmBxSB & b flt 4454-4666(212), Tqm 4666-4806(140), P€pi 4806-5154(348) T.D.
Unknown				
C-1 SE¼NE¼SE¼ Sec. 14 T1S, R13E	Not reached	Not reached		Not reached
C-2 NE¼NE¼SE¼ Sec. 14 T1S, R13E	Not reached	Not reached		Not reached
United Verde				
U-1 SW¼NW¼NW¼ Sec. 12 T1S, R13E	—	—		P€pibx 711-780(69) T.D.
U-2 SW¼NW¼NW¼ Sec. 12 T1S, R13E	—	—		P€pi-Tqm Bx 737-1146(409) T.D.
U-3 NW¼SW¼NW¼ Sec. 12 T1S, R13E	—	—		Tqm Bx 625-875(250) T.D.
U-4 SW¼NE¼NE¼ Sec. 2 T1S, R13E	—	—		P€piBx 1235-1600(365) T.D.
U-5 SE¼NE¼NE¼ Sec. 2 T1S, R13E	—	—		P€piBx 488-835(347) T.D.

Explanation of abbreviated units.

Tbfp	Tertiary biotite feldspar porphyry	Tw	Tertiary Whitetail Conglomerate	P€t	Precambrian Troy Quartzite
Tqfp	Tertiary quartz feldspar porphyry	Psupai	Permian Supai Formation	P€pi	Precambrian Pinal Schist
Tqmp	Tertiary quartz monzonite porphyry	Pnaco	Pennsylvanian Naco Formation	Bx	breccia or brecciated
Tqm	Tertiary quartz monzonite	Me	Mississippian Escabrosa Limestone	SB	slide block
Tap	Tertiary aplite	Dm	Devonian Martin Formation	b flt	basal fault
Tgr	Tertiary granite	€b	Cambrian Bolsa Quartzite	vn	vein
Tbx	Tertiary breccia	P€db	Precambrian diabase	seds	sediments, undifferentiated

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