A Geologic Tour of the Ray Copper Deposit and the Kelvin Copper Prospect Pinal County, AZ

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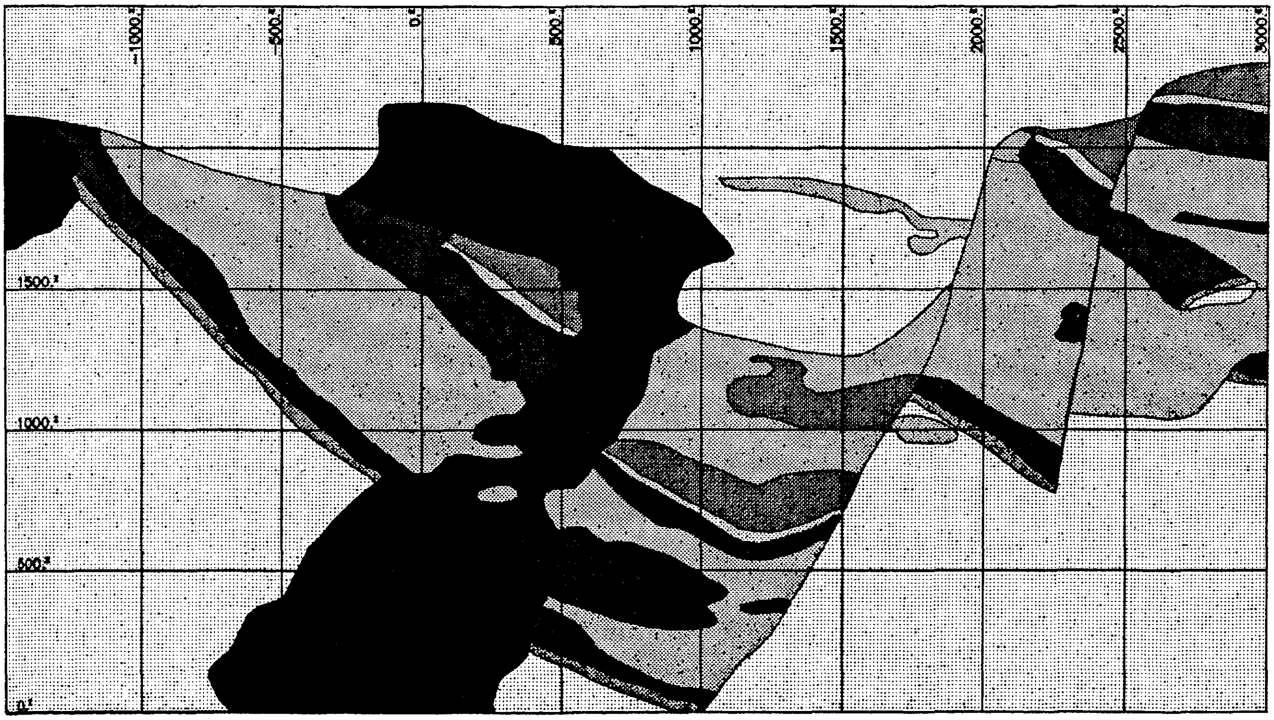
Edited by Mark Miller



Guidebook for the
Arizona Geological Society
Spring Field Trip
April 16, 1994

Arizona Geological Society
PO Box 40952 Tucson, AZ 85717

April 16, 1994

Dear Field Trip Participant,

Welcome to the 1994 spring field trip of the Arizona Geological Society. We will be visiting the Asarco Ray copper mine in the morning and the Kelvin porphyry copper prospect in the afternoon.

As you drive up to the mine from Oracle Junction, be sure to read the road log by William Dickinson which describes the geology along the route.

Ed John, Senior Geologist at Ray will host the morning trip. Ray Mine is a porphyry copper deposit hosted in Precambrian Pinal Schist and sediments of the Apache Group. These have been intruded by Precambrian diabase sills and were later intruded by the Granite Mountain porphyry of Laramide age—the probable source of the mineralizing solutions.

The reserves currently published at Ray are 1.1 billion tons @ .60% copper. The ore is extracted by open pit mining and both SX-EW copper and copper concentrates are produced. Ray recently underwent an expansion that doubled production to the current 60,000 TPD with the addition of a new concentrator at the mine site, in-pit crushing, and a new tailings pond.

In the afternoon, we will be visiting the Kelvin copper prospect. This trip will be hosted by Russell Corn and Richard Ahern who are former Kerr McGee exploration geologists who worked in the Kelvin area and currently control exploration ground there. They will be describing the complex geologic and structural history of the Kelvin deposit, a sliced-up and structurally extended alteration/mineralization system.

I would like to thank the authors, Ed John, Bill Dickinson, Russell Corn, Richard Ahern, and Eric Force for their contributions to the guidebook and their field presentations.

I would also like to personally thank Rob Vugteveen, Asarco-Tucson for his help and guidance in the organization and desktop publishing of this guidebook.

So, sit back, enjoy the ride, and be prepared for an interesting and informative field trip.

Mark Miller
Editor

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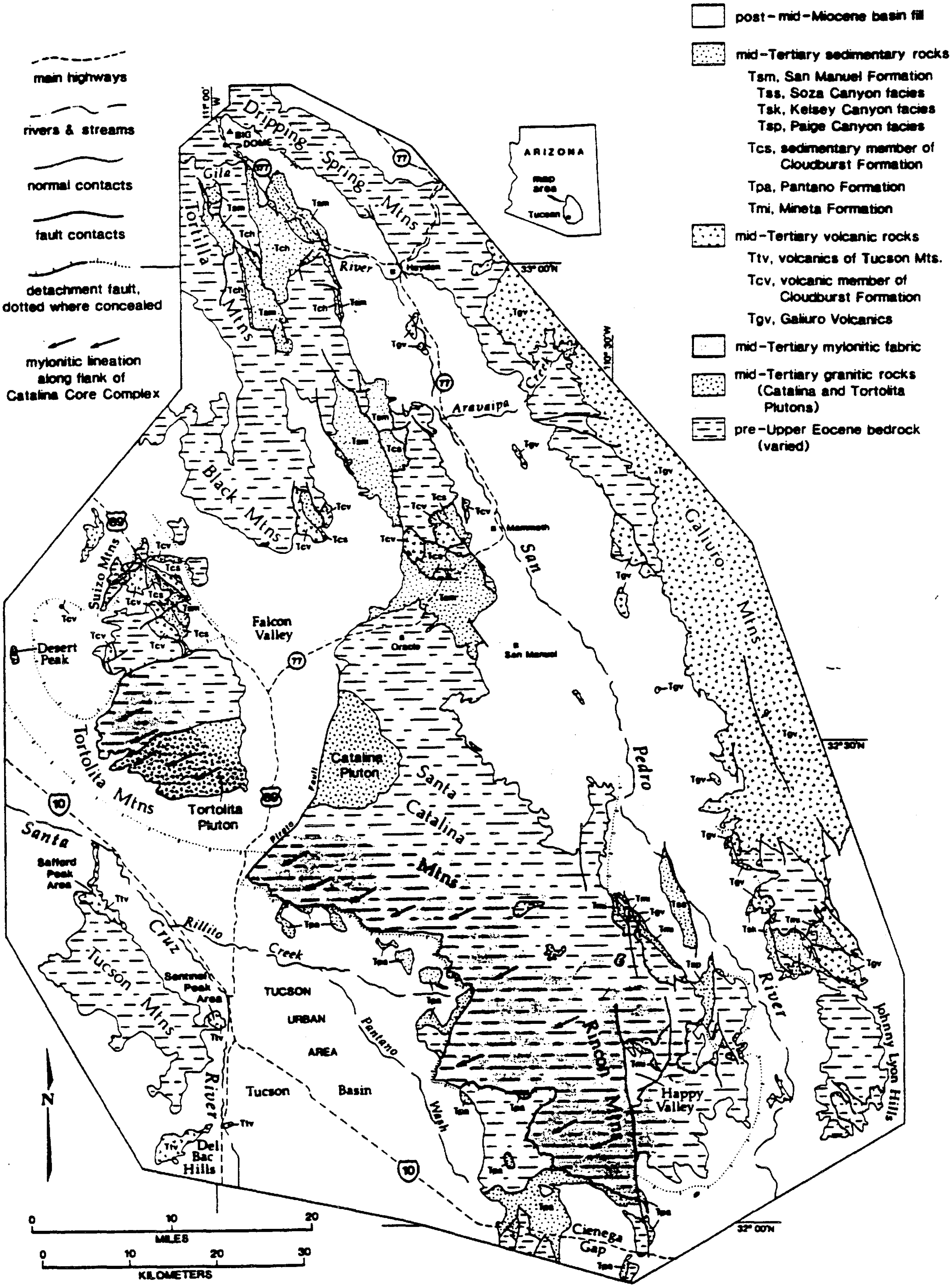

Geologic sketch map of Catalina core complex (mylonitic foliation and lineation along southwest flank) and San Pedro trough (traversed by San Pedro River and by Gila River below their confluence) showing areal distribution of tilted homoclines of mid-Tertiary volcanic and sedimentary successions in relation to exposures of older bedrock and younger basin fill; modified after Dickinson and Shafiqullah (1989).

GEOLOGIC ROAD LOG,
ORACLE JUNCTION TO RAY MINE, ARIZONA

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This guide was prepared as an entry log for the 1994 spring field trip of the Arizona Geological Society to the Ray Mine and does not include any stops, but at least limited parking space is available at all the geologic features and viewpoints noted. Unless otherwise indicated, information included in the guide is extracted from GSA Special Paper 264 (Dickinson, 1991), an AzGS contributed map of the Black Hills (Dickinson, 1993a), and the 1993 AGS spring field trip guidebook (Dickinson, 1993b). As the mileage log was run while reconstruction of the highway intersection at Oracle Junction was still underway, mileages should be rechecked for accuracy at the next couple of road intersections along the route of travel. The preceding illustration (Figure 2 of Dickinson, 1991) shows the general route of travel from Oracle Junction (at the intersection shown in Falcon Valley) across the drainage divide at Oracle (mile 11) to Mammoth (mile 23), thence down the San Pedro River to the Gila River (mile 43) near Hayden, and down the Gila River to the Ray Mine Gate (mile 60) near Big Dome. The assembly point at Oracle Junction is located on a terrace surface underlain by Neogene basin fill near Big Wash, which drains south toward the Santa Cruz River. Three bedrock ranges are visible on the skyline from Oracle Junction:

(a) To the north, low peaks of the Black Mountains are just visible rising above Falcon Divide, a deeply weathered but essentially undissected remnant of the upper surface of Neogene basin fill. Falcon Divide is a relict intermontane valley of the paleolandscape that existed prior to the integration of the Gila River drainage system into the Gulf of California late in Miocene time. Three tributary streams of the Gila network are currently working headward into the flanks of Falcon Divide (Coronado Wash from the west, Camp Grant Wash from the northeast, and Big Wash from the south). The Black Mountains are composed dominantly of Middle Proterozoic (1420-1450 Ma) porphyritic granite of the Oracle/Ruin suite, together with local pendants and screens of Lower Proterozoic Pinal Schist (pre-1700 Ma depositional age of protolith). The characteristic megacrystic granite lithology has been mapped as both Oracle Granite (name from the nearby town of Oracle) and Ruin Granite (name from Ruin Basin near Miami) along the field trip route.

(b) To the east is the steep western face of the Santa Catalina Mountains controlled by the position of the north-south Pirate fault, which separates bedrock of the Catalina core complex on the east from the basin fill of Oro Valley to the west. Gravity data establish the presence of an asymmetric wedge of basin fill thickening toward the Pirate fault to a maximum estimated thickness of 1500 m. Combining the depth of basin fill adjacent to the range front with the relief from the valley floor to the range crest suggests a vertical throw of nearly 5 km for the Pirate fault. In detail, however, the Pirate fault trace does not mark a sharp topographic break because pediment surfaces have been cut into the edge of the uplifted bedrock block since the major fault movements occurred, perhaps during the interval 6-12 Ma (Late Miocene) from regional relations. Features visible within the mountain block include the north-south Samaniego Ridge, standing in front of the domical Mount Lemmon massif of the Catalina main range and underlain by Late Oligocene (26 Ma) Catalina Granite. Several jagged peaks of the Catalina forerange to the south (Cathedral Peak, Mount Kimball, and Pusch Ridge from left to right) are composed of foliated and lineated mylonitic gneiss. The protolith for most of the mylonitic rock within view was peraluminous two-mica granite of the Eocene Wilderness suite (45-50 Ma). The terrace-like risers in the foreground within the Oro Valley block are distal finger-like ridges of the bifurcating Cordonnes surface, a dissected Pleistocene alluvial fan built into Oro Valley by the Canada del Oro before it was diverted along the Pirate fault trend by differential erosion.

(c) To the west, the Tortolita Mountains segment of the Catalina core complex presents a much lower profile than the Santa Catalina Mountains, and may indicate by its subdued relief the typical morphology of the core complex in mid-Miocene time, after detachment faulting but prior to offsets along the Pirate fault. The Catalina core complex is bounded along its southwest flank by the Catalina detachment fault system, which has been traced along strike for about 125 km, from Cienega Gap east of Tucson to Picacho Peak near the freeway northwest of Tucson.

0.0 Oracle Junction restaurant and cafe.

0.1 Junction of Highways 77 and 79. Heading north, the road climbs a ramplike sedimented slope to the paleosurface of Falcon Divide. The route follows an incised pediment surface, cut into basin fill, that merges gradually with outliers of the Cordonnes surface as elevation is gained.

5.0 Willow Springs Road (on left); small conical peak at 9:30 in front of Pinal Mountains on skyline is Antelope Peak, an inselberg of Middle Proterozoic Oracle/Ruin Granite rising above the level of an intermontane pediment surface near the head of Putnam Wash. Approximately 15 km north of this intersection, along the eastern flank of the Black Mountains in the Star Flat-Willow Springs area (Dickinson, 1994), are exposures of the Star Flat extensional allochthon above the subhorizontal Star Flat detachment fault. The allochthon is composed of 1750-2250 m of Cloudburst Formation (Upper Oligocene volcanosedimentary strata) dipping 60-80 degrees eastward into Oracle/Ruin Granite below the detachment fault. The strata of Cloudburst Formation forming the Star Flat allochthon are overlain unconformably near the Willow Springs Ranch by more gently dipping (5-15 degrees) and less indurated Lower Miocene conglomeratic strata of the San Manuel Formation (125-175 m are preserved above the buttress unconformity), and also by undeformed (dip less than 5 degrees) basin fill, the "gravels of Camp Grant Wash". Farther east in the Black Hills near

Mammoth, strata of the Cloudburst Formation include a volcanic lower member (partial sections are 1200-1500 m thick) overlain gradationally by the sedimentary upper member (fanglomerate about 1750 m thick) within the Tar Wash extensional allochthon, which is floored by the gently dipping (less than 5 degrees) Cloudburst detachment fault and is offset by the low-angle San Manuel normal fault. The Star Flat and Cloudburst faults are evidently imbricate listric splays of a complex detachment system, and each apparently offsets the rotated strata of the Cloudburst Formation as much as 5-10 km, toward the WSW away from the Galiuro Mountains, where mid-Tertiary volcanics correlative with the volcanic lower member of the Cloudburst Formation are extensively exposed and nearly flatlying (dips <10 degrees).

5.6	Turnoff to Biosphere II (on right).
6.8	Contact between Neogene gravel and Oracle/Ruin Granite as road passes almost imperceptibly from basin fill to exhumed and slightly dissected bedrock pediment, which appears to be graded to the level of the top of basin fill on the Falcon Divide paleosurface.
9.2	Southernmost turnoff to Oracle (on right).
9.5	Picturesque outcrops of Oracle/Ruin Granite on left (exfoliated boulders weathering spheroidally in place).
10.5 & 11.0	Roadcuts in weathered Oracle/Ruin Granite cut by dikes of comagmatic aplopegmatite.
11.8	Beginning of descent into San Pedro structural trough, drained by axial San Pedro River, with Galiuro Mountains capped by mid-Tertiary (23-29 Ma) Galiuro Volcanics on skyline, and Santa Teresa Mountains visible locally behind Galiuro Range.
12.35	Northernmost turnoff to Oracle (on right); road continues descent through low hills of weathered Oracle/Ruin Granite.
13.2	Old highway (on left) leads to "Purcell Window" of basement rocks exposed directly above Kalamazoo orebody (offset segment of San Manuel porphyry copper system).
13.5	Depositional contact between Oracle/Ruin Granite and Lower Miocene San Manuel Formation (22-16 Ma); note huge boulders of Oracle/Ruin lithology on hillside ahead to left weathering out of coarse gravels in basal San Manuel Formation.

14.0 Excellent outcrops of Kannally Member of San Manuel Formation on curve and in Cherry Valley Wash below road. Kannally Member (the lower of two members) is 750-1750 m thick, dips 15-30 degrees northeast into the San Manuel fault, and is composed dominantly of Oracle/Ruin detritus deposited on an alluvial fan or braidplain by paleocurrents flowing to N60-65E (net paleoflow vector from imbrication).

15.2 Traversing dissected pediment cut across dipping San Manuel Formation, with pockets of pediment gravel preserved locally; cliffs of Table Mountain on skyline ahead underlain by nearly flat-lying ash-flow tuffs of Galiuro Volcanics.

16.6 Copper Creek drainage visible to the right of Table Mountain exposes in its headwater region a porphyry copper system associated with Laramide (65-70 Ma) volcanic and intrusive rocks in the Copper Creek (Bunker Hill) Mining District (Creasey and others, 1981). Farther downstream, across a faulted contact flanking the San Pedro trough, the steep walls of Copper Creek canyon expose a transect through subparallel facies belts of the Quiburis Formation, which is the basin fill of the San Pedro trough. Fanglomerate near the range front passes basinward into marginal-lacustrine sand-flat deposits, forming a belt about 2 km wide, in front of which are laminated lakebeds that accumulated along the axis of the trough. Exposed horizons of the Quiburis Formation are Late Miocene or younger, but buried horizons may be as old as mid-Miocene.

17.4 Junction (overpass) with San Manuel Road. Headframes of underground mine and waste dumps of open pit visible on left. Smelter stack visible on right.

17.6 Gradational contact between Kannally and Tucson Wash Members of San Manuel Formation in low cuts and shallow gullies beside road. Tucson Wash Member locally grades laterally into but generally overlies Kannally Member. Dispersal directions for the two members are almost exactly opposed, so progradation of the Tucson Wash Member progressively restricted the area of Kannally Member deposition.

18.35 High roadcut in Tucson Wash Member of San Manuel Formation. Tucson Wash Member (the upper of two members) is 750-1000 m thick, dips (near the highway) 25-45 degrees northeast into the San Manuel fault, contains abundant clasts of Upper Oligocene volcanic and volcaniclastic rocks (reworked from the Galiuro Volcanics or the generally correlative volcanic lower member of the Cloudburst Formation), and was deposited on an alluvial fan or braidplain by paleocurrents flowing to S55W (net paleoflow vector from imbrication).

18.85	Contact with reddish Oracle/Ruin Granite near small ravine marks trace of San Manuel fault, a rotated low-angle normal fault that now dips 25-45 degrees WSW (ave. 30-35 degrees), but probably dipped 60-75 degrees during initial displacements. Net slip about 2.5 km based on offset of a porphyry copper system from the San Manuel mine (footwall) to its Kalamazoo extension (hanging wall). Synchroneity of slip with deposition of San Manuel Formation is implied by restriction of Kannally Member to hanging wall but overstep of San Manuel fault by Tucson Wash Member, which rests locally on footwall bedrock. Recent analyses of the tilt and offset of the orebodies are discussed in detail by Force and Cox (1992), and Force and Dickinson (1993, 1994).
18.95	Buttress unconformity of tilted Quiburis Formation (alluvial fan facies) on Oracle/Ruin Granite along the paleoscarp of the buried Cholla fault, a high-angle basin-range normal fault dipping 60 degrees east in exposures only 1 km to the north near Mammoth Wash. In general, displacements on individual basin-range faults flanking the San Pedro trough are estimated as no more than 250 m, and are locally antithetic as well as synthetic to the trough flanks. Slip was evidently synchronous with deposition of the Quiburis Formation, which is offset by many of the faults but also onlaps and oversteps eroded fault scarps.
20.6	Railroad crossing.
20.7	White bluffs across San Pedro river floodplain on right are exposures of lacustrine facies of Quiburis Formation along axis of San Pedro trough. Tuffs intercalated nearby have yielded Late Miocene (5.4-6.4 Ma) radiometric ages (K-Ar, WR, glass).
21.1	Crossing the Mammoth Wash with exposures of alluvial fan facies of Quiburis Formation in flanking cutbanks (record of fans built eastward from Black Hills toward the axial lacustrine facies of the San Pedro trough).
21.8	Southernmost turnoff to Mammoth (on right).
22.75	Marginal-lacustrine sand-flat facies of Quiburis Formation (in lower part of roadcut on left opposite a Circle K store) unconformably underlies San Pedro River terrace gravels exposed along the top of the roadcut; sand-flat deposits form a facies belt west of laminated lacustrine facies but still east of alluvial fan facies derived from the Black Hills.
23.2	Northernmost turnoff to Mammoth (on right).
23.4	Resistant butte cappings at tops of bluffs near city park behind Chevron

station on left are indurated San Pedro River terrace gravels (of probable Pleistocene age), which rest unconformably on marginal-lacustrine sand-flat facies of Quiburis Formation exposed in lower parts of bluffs.

23.6 Mouth of Tucson Wash at outskirts of Mammoth, with Table Mountain and Holy Joe Peak (the small cliffed outlier known locally as "Collar Button") on skyline to right. Holy Joe Peak is capped by the Holy Joe Member, the most distinctive ash-flow tuff sheet of the Galiuro Volcanics (Krieger, 1979).

24.1 Visible downstream on left from bridge over San Pedro River are additional low buttes capped by San Pedro River terrace gravels, in this case overlying alluvial fan facies of Quiburis Formation.

24.6 Junction (on right) with road down east side of San Pedro River floodplain.

24.7 Bluff on right exposes San Pedro River fill-terrace gravel, which documents a valley history involving incision, then backfilling by aggradation, then renewed incision to excavate the fill.

24.9 Analogous bluff of fill terrace materials on right, with intercalated lens of tawny floodplain sand interbedded with the river gravels. Ahead, the low bluffs beside the road are composed of terrace gravels, but outcrops of Quiburis Formation are visible short distances up the small canyons on the right. Across the floodplain of the San Pedro River to the left, the alluvial fan facies of the Quiburis Formation underlying the slopes onlaps bedrock of the Tortilla Mountains forming the skyline.

27.7 Track up Zapata Wash on right leads toward Holy Joe Peak through the eroded crest of an exhumed tiltblock within the San Pedro trough. Exposures of the tiltblock lie about 5 km from our route and include Holy Joe Member tuff dipping 25 degrees ENE toward the Galiuro Mountains, where equivalent strata dip just 10 degrees or less to the northeast only 10 km beyond the tiltblock (Krieger, 1968a). The eroded flanks of the exhumed tiltblock are delimited by buttress unconformities where Quiburis lakebeds onlap old erosional surfaces marked by up to 5 m of buried talus breccias. Within the San Pedro trough, Quiburis sedimentation evidently buried a corrugated paleotopography of tiltblock crests and intervening half-graben sub-basins. Pliocene and younger dissection following integration of the San Pedro trough into the Gila River drainage has partially exhumed some of the buried tiltblocks.

29.9 River terrace sand with gravel lenses unconformably above dipping Quiburis beds near road level.

31.9	Aravaipa Creek. Mouth of Putnam Wash across San Pedro River on left. Hills north of Putnam Wash expose a Middle Proterozoic sequence of Apache Group and Troy Quartzite resting depositionally on Pinal Schist and Oracle/Ruin Granite intruded by voluminous Precambrian diabase sills (1100 Ma), unconformably overlain by a Paleozoic succession, and cut by a tilted Laramide thrust (Krieger, 1968b). The Precambrian and Paleozoic strata, and the tilted thrust, all dip 35-55 degrees to the northeast. The quarrying operation ships Troy Quartzite by rail as flux to the San Manuel smelter (Houser, 1992).
32.4	Aravaipa Road (on right), built on ancestral fan of Aravaipa Creek.
33.5	Side road (on right) to gypsum quarry in Quiburis lakebeds underlying terraces and low hills to right. Tablelands north of Aravaipa Canyon now form the skyline on the right.
34.8	Gypsiferous Quiburis outcrop at road level, with younger terrace gravels exposed above; other outcrops of Quiburis lakebeds in tan bluffs across San Pedro River floodplain to left.
35.9	Roadcuts expose Quiburis lacustrine facies overlain by San Pedro River terrace gravels.
36.4	Dudleyville turnoff (on left), with San Pedro River terrace gravels in roadcuts just ahead. The prominent elongate low hill of dark hue just across the San Pedro River on the left is Malpais Hill, a partly exhumed tiltblock of Galiuro Volcanics dipping 30 degrees ENE. Onlapping Quiburis lakebeds flanking the north side of Malpais Hill are visible from our route along the highway.
38.4	Lacustrine facies of Quiburis Formation reappears from beneath river terrace gravels in roadcuts.
38.7	Eskiminzin Wash. The line of low hills ahead on the left is yet another exhumed tiltblock of Galiuro Volcanics within the San Pedro trough.
38.8 & 39.5	Outcrops of pebbly sand and sandy gravel in Quiburis Formation opposite both old and new sites of market are interpreted as deltaic facies that prograded longitudinally down the axis of the San Pedro trough from the fluvial tract occupying the Gila River valley (ahead) into the lacustrine tract occupying the San Pedro River valley (behind).
39.8	Steep hill on left is another tiltblock of Galiuro Volcanics, again dipping 30 degrees ENE, exhumed from beneath Quiburis Formation that overlies buttress unconformities flanking the tiltblock (laminated sandy Quiburis

Formation is exposed at road level in roadcut on right).

40.1 Pebbly/sandy deltaic facies of Quiburis Formation exposed in cuts on both sides of road (smelter stack at Hayden straight ahead); Quiburis strata become progressively coarser grained ahead. The crest of the Crozier Peak spur of the Tortilla Mountains forms the skyline on the left. The ridge is flanked by onlapping beds of Quiburis Formation, as well as by superimposed modern fans and pediments. Beneath this basin fill, tilted beds (25-45 degree dips) of mid-Tertiary strata (Cloudburst and San Manuel Formations) are preserved as a thin succession dipping eastward off the Crozier Peak spur, which is thus itself a large tiltblock.

40.3 Saddle Mountain, an outlier of Galiuro Volcanics (Krieger, 1968c), is visible on the skyline to the right.

41.9 Midway through the roadcut on the left is a key contact between well-bedded but subangular and indurated pebble conglomerate of the Quiburis Formation (to the south) and an unconformable capping (to the north) of less consolidated but better rounded yet more rudely bedded San Pedro River stream terrace gravel of younger age. The Quiburis gravel is composed mainly of volcaniclastic debris derived from the Williamson Canyon Volcanics of Laramide age (75-80 Ma) in the Dripping Spring Mountains and Gila River canyon to the north, whereas the San Pedro River terrace gravels are more polymictic, with varied basement clasts derived from terrain to the south.

42.75 Last roadcuts before Gila River expose mainly San Pedro River terrace gravels, but Quiburis outcrops occur locally near road level. Contiguous outcrops in the low hills across the river at the base of the Hayden stack were mapped as Quiburis Formation in the Winkelman Quadrangle (Krieger, 1974), then later as "Big Dome Formation" in the adjacent Hayden Quadrangle (Banks and Krieger, 1977). Recognition of the "Big Dome Formation" as a stratigraphic unit younger than the San Manuel Formation but older than the Quiburis Formation (Krieger, 1974b; Krieger and others, 1974) was based on inaccurate dating of an ash-flow tuff near Kearny (Dickinson and Shafiqullah, 1989). The main body of the type "Big Dome Formation" along the valley of the Gila River (forming a northern extension of the San Pedro trough) is treated here as a northern alluvial facies of the Quiburis Formation, but lower portions of the "Big Dome Formation" are assigned to the San Manuel Formation on the basis of both lithology and age. The west base of the prominent ridge of Paleozoic limestone beyond the Hayden stack is delineated by a fault, along which the basin fill of Quiburis Formation within the Gila River valley segment of the San Pedro trough is downfaulted against Paleozoic bedrock.

43.0 Bridge over Gila River. Houses in the Winkelman Flats area on right were destroyed by the great flood of early 1993.

43.2 Turn left at junction of highways 77 and 177 in Winkelman.

44.0 Exposure of dark volcaniclastic conglomerate of the Quiburis Formation.

44.7 Road to Hayden (on right).

45.1 Exposure of Quiburis conglomerate and sandstone, overlain unconformably ahead by caps of younger terrace gravels.

46.7 Exposure of stream terrace gravels (unconformable above Quiburis Formation) in roadcut below water tank.

47.3 North end of Crozier Peak spur of Tortilla Mountains across Gila River to left.

49.2 Approximate contact between Quiburis and San Manuel Formations (partly obscured by terrace gravel cover).

49.4 Roadcut in sandy granitic detritus of San Manuel Formation.

50.2 Dipping pink ash-flow tuff ledge within San Manuel Formation is exposed up side gulch to right. Farther west near Kearny, the same tuff layer has yielded an isotopic age of 19-20 Ma (K-Ar, biotite), and is regarded here as distal Apache Leap Tuff (the southernmost known occurrence of that unit, widespread north of the Gila River toward Superior and Globe). Previous discordant isotopic ages (17 Ma, hornblende; 14 Ma, biotite) for this tuff led to recognition of a supposed "Big Dome Formation". The bulk of the "Big Dome formation", regarded here as a facies of the Quiburis Formation, contains reworked clasts of reddish Apache Leap Tuff as a diagnostic lithologic feature.

50.3 High roadcut on curve exposes granitic gravel of San Manuel Formation near road level, with terrace gravel above.

51.1 Tawny bluffs of gently tilted San Manuel Formation on right beyond field nestled within curved re-entrant of Gila River floodplain. Gray benchlands beyond the bluffs are underlain by overlying Quiburis Formation above a concordant contact marked by condensed paleosols. A sharp but concordant contact between San Manuel Formation and the underlying Hackberry Wash facies of the Cloudburst Formation lies on the far side of the low ridge just beyond the Gila River channel to the left. Dripping Spring Mountains on right skyline and Ripsey Hill spur of Tortilla

Mountains on left skyline.

52.3 Basal San Manuel Formation exposed in bluffs just across Gila River to left.

53.0 Entrance to the town of Kearny, perched on fan terraces above the Gila River floodplain. The big drainage opening up across the Gila River to the south is Hackberry Wash, lying between parallel spurs of the Tortilla Mountains. Along Hackberry Wash, a thick east-dipping homocline of mid-Tertiary strata fans upward from dips of 60-70 degrees near its base in the Upper Oligocene Hackberry Wash Facies (2000 m) of the Cloudburst Formation to dips of 25-35 degrees in the Lower Miocene San Manuel Formation (1250 m) near the Gila River. Bold flatiron outcrops ahead on the left on the flank of the Ripsey Hill tiltblock are limestone-clast debris-avalanche megabreccias (Krieger, 1977) in the Hackberry Wash Facies of the Cloudburst Formation. The picturesque peak on the skyline directly ahead is Teapot Mountain immediately west of the Ray Mine. The high crest of the Dripping Spring Mountains lies to the right (north).

54.7 Old Ray Road (on right) provides access to dated tuff locality in San Manuel Formation (Cornwall and Krieger, 1975; Dickinson and Shafiqullah, 1989).

55.3 Roadcut exposes San Manuel Formation below terrace gravel cap.

55.5 Approximate contact between San Manuel Formation and Quiburis Formation.

55.7 Roadcut exposes Quiburis Formation containing reddish clasts of Apache Leap Tuff. Ripsey Hill on skyline to left across Gila River.

56.4 Kelvin Road (on left), with Ray Mine workings now visible straight ahead.

57.6 Narrow slot canyon just before right-hand curve. Town of Riverside visible across Gila River to left at north end of Ripsey Hill spur of Tortilla Mountains.

57.9 Passing down across nonconformity (in low swale) between Quiburis Formation and Oracle/Ruin Granite.

58.1 Passing up across buttress unconformity, exposed in roadcut on right, between Oracle/Ruin Granite and overlying beds of Quiburis Formation.

58.5 Passing down across poorly exposed nonconformity between basal Quiburis Formation and Oracle/Ruin Granite.

59.4 Bridge over Mineral Creek, which drains into the Gila River form the Ray Mine area. Big Dome rock and the Ray Mine workings are visible ahead on the right.

59.7 Outcrop of Laramide (70-75 Ma) Tortilla Quartz Diorite on left beside road; alluvial fan facies of Quiburis Formation composed dominantly of Tortilla Quartz Diorite clasts is exposed just ahead on the hillside beyond the Ray Mine Road (Cornwall and others, 1971).

59.9 Ray Mine Road (turn right).

60.0 Ray Mine Gate at end of entry road log.

REFERENCES CITED

Banks, N.G., and M.H. Krieger, 1977, Geologic map of the Hayden quadrangle, Pinal and Gila Counties, Arizona: U.S. Geological Survey Geologic Quadrangle Map GQ-1391, scale 1:24,000 with 15 p. text.

Cornwall, H.R., and M.H. Krieger, 1975, Geologic map of the Kearny quadrangle, Pinal County, Arizona: U.S. Geological Survey Geologic Quadrangle Map GQ-1188, scale 1:24,000 with 9 p. text.

Cornwall, H.R., N.G. Banks, and C.H. Phillips, 1971, Geologic map of the Sonora quadrangle, Pinal and Gila Counties, Arizona: U.S. Geological Survey Geologic Quadrangle Map GQ-1021, scale 1:24,000.

Creasey, S.C., J.E. Jinks, F.E. Williams, and H.C. Meeves, 1981, Mineral resources of the Galiuro Wilderness and contiguous further planning areas, Arizona: U.S. Geological Survey Bulletin 1490, 94 p.

Dickinson, W.R., 1991, Tectonic setting of faulted Tertiary strata associated with the Catalina core complex in southern Arizona: Geological Society of America Special Paper 264, 106 p. [map available separately as Dickinson, 1992].

Dickinson, W.R., 1992, Geologic map of Catalina core complex and San Pedro trough, Pima, Pinal, Gila, Graham, and Cochise Counties, Arizona: Arizona Geological Survey Contributed Map CM-92-C, scale 1:125,000 [map from Dickinson, 1991].

Dickinson, W.R., 1993a, Summary geologic map of Black Hills near Mammoth, Pinal County, Arizona: Arizona Geological Survey Contributed Map CM-93-B, scale 1:24,000.

Dickinson, W.R., 1993b, Tertiary structures and stratigraphic units in the Black Hills between Oracle and Mammoth, Pinal County, Arizona: Arizona Geological Society Spring Field Trip Guidebook, 4 p.

Dickinson, W.R., 1994, Geologic map of Star Flat-Willow Springs area, Pinal County, Arizona: Arizona Geological Survey Contributed Map CM-94-B, scale 1:24,000 with 3 p. text.

Dickinson, W.R., and M. Shafiqullah, 1989, K-Ar and F-T ages for syntectonic mid-Tertiary volcanosedimentary sequences associated with the Catalina core complex and San Pedro trough in southern Arizona: Isochron/West, No. 52, p. 15-27.

Force, E.R., and L.J. Cox, 1992, Structural context of mid-Tertiary mineralization in the Mammoth and San Manuel districts, southeastern Arizona: U.S. Geological Survey Bulletin 2042-C, p. C1-C28.

Force, E.R., and W.R. Dickinson, 1993, New work in the San Manuel and Mammoth districts (Pinal County, Arizona), an introduction via Tucson Wash: Arizona Geological Society Spring Field Trip Guidebook, 24 p.

Force, E.R., and W.R. Dickinson, 1994, Tucson Wash an introduction to new work in the San Manuel and Mammoth districts, Pinal County, Arizona, in Thorman, C.H., and D.E. Lane (eds.), USGS research on mineral resources 1994; Part B guidebook for field trips: U.S. Geological Survey Circular 1103-B, p. 103-115.

Houser, B.B. (ed.), 1992, Industrial minerals of the Tucson area and San Pedro Valley, southeastern Arizona: Arizona Geological Society Spring Field Trip Guidebook, 55 p.

Krieger, M.H., 1968a, Geologic map of the Holy Joe Peak quadrangle, Pinal County, Arizona: U.S. Geological Survey Geologic Quadrangle Map GQ-669, scale 1:24,000 with 4 p. text.

Krieger, M.H., 1968b, Geologic map of the Lookout Mountain quadrangle, Pinal County, Arizona: U.S. Geological Survey Geologic Quadrangle Map GQ-670, scale 1:24,000 with 2 p. text.

Krieger, M.H., 1968c, Geologic map of the Saddle Mountain quadrangle, Pinal County, Arizona: U.S. Geological Survey Geologic Quadrangle Map GQ-671, scale 1:24,000 with 3 p. text.

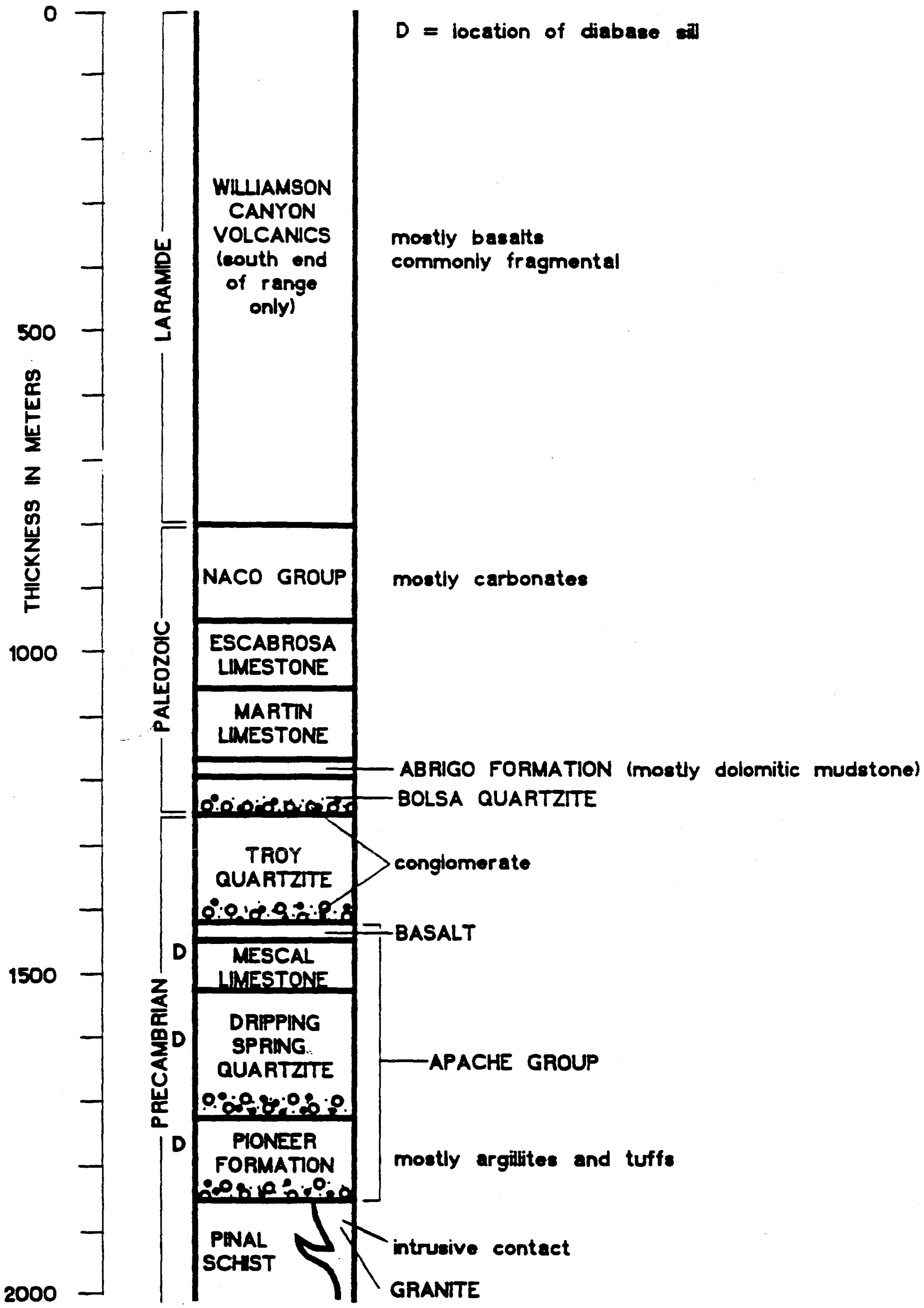
Krieger, M.H., 1974a, Geologic map of the Winkelman quadrangle, Pinal and Gila Counties, Arizona: U.S. Geological Survey Geologic Quadrangle Map GQ-1106, scale 1:24,000 with 8 p. text.

Krieger, M.H., 1974b, Generalized geology and structure of the Winkelman 15-minute quadrangle and vicinity, Pinal and Gila Counties, Arizona: U.S. Geological Survey Journal of Research, v. 2, p. 311-321.

Krieger, M.H., 1977, Large landslides, composed of megabreccia, interbedded in Miocene basin deposits, southeastern Arizona: U.S. Geological Survey Professional Paper 1008, 25 p.

Krieger, M.H., 1979, Ash-flow tuffs of the Galiuro Volcanics in the northern Galiuro Mountains, Pinal County, Arizona: U.S. Geological Survey Professional Paper 1104, 32 p.

Krieger, M.H., H.R. Cornwall, and N.G. Banks, 1974, Big Dome Formation and revised Tertiary stratigraphy in the Ray-San Manuel area, Arizona: U.S. Geological Survey Bulletin 1394-A, p. A54-A62.



Composite Stratigraphy of the Dripping Spring Range
by Eric Force, 1994

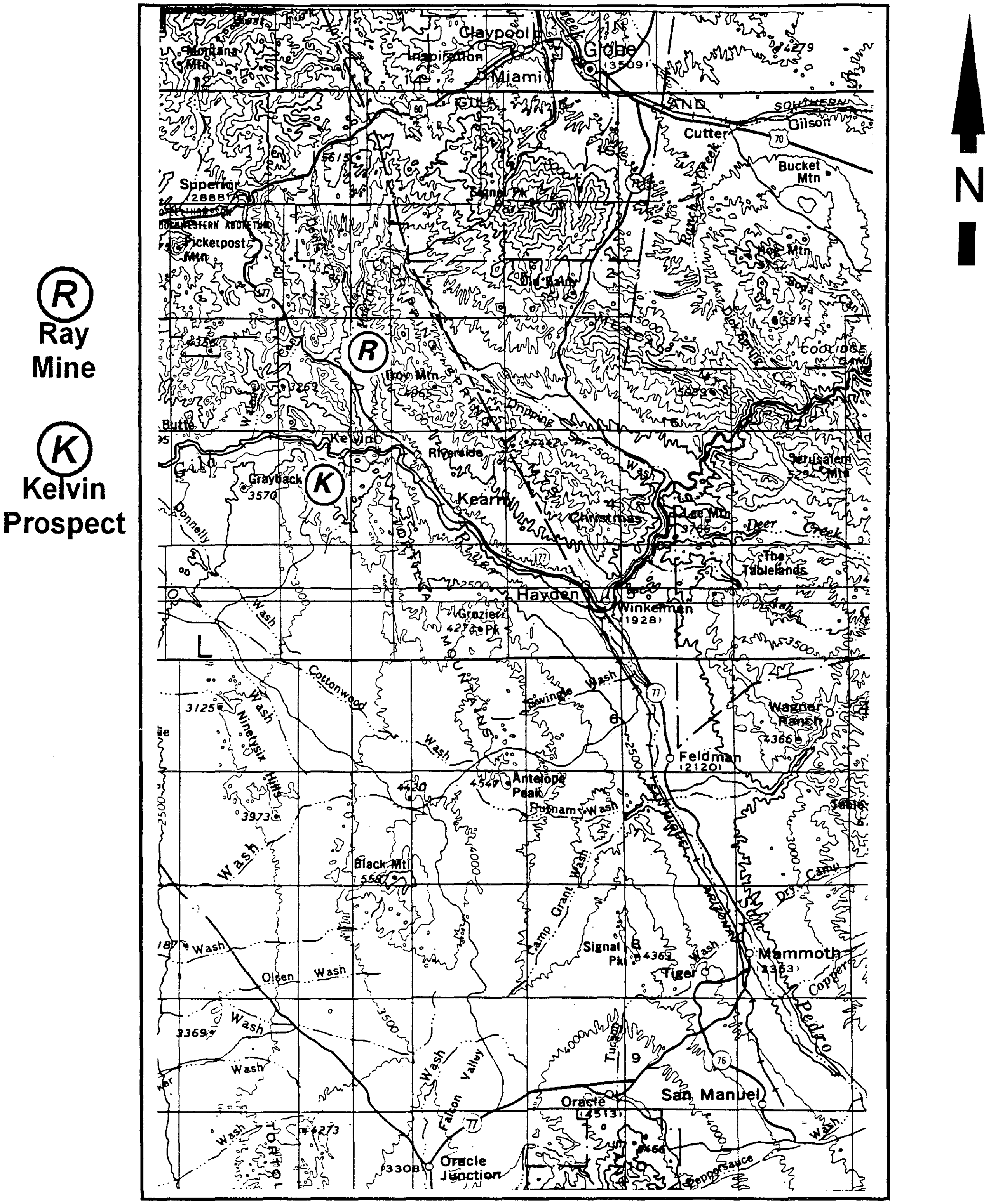


FIGURE 1

Index Map to the Ray Mine and Kelvin Prospect

adapted from U.S.G.S. Arizona Base Map

GEOLOGY OF THE RAY PORPHYRY COPPER DEPOSIT PINAL COUNTY, ARIZONA

Ed John, Senior Geologist, Asarco Ray Mine

The Ray Mine, owned and operated by ASARCO Incorporated is located in eastern Pinal County, Arizona, seventy miles southeast of Phoenix. Ray is a large, classic porphyry copper deposit. The deposit has been a major source of copper since 1911, producing an estimated 4.1 million tons of copper. Mining was accomplished underground by block caving and shrinkage stope methods until 1955 when the operation was converted to an open pit. The bulk of the production has been from sulfide ore with recovery by concentrating and smelting. However, since 1969 a significant contribution has been made by leaching of silicate and oxide ores, recovering the copper by the solvent extraction-electrowinning method. Reserves have been published as 1.1 billion tons at 0.6 percent copper. (Figure 1)

The Ray deposit was found by prospectors. Therefore, early geological studies were directed at defining reserves, optimizing mineral recovery, and aiding mining practice. An ideal deposit is homogeneous and isotropic where mining and milling practice can be standardized. Ray geology does not cooperate. It is complex and always full of surprises. Mineralization is controlled by rock type, position within the deposit, faulting, and enrichment history.

STRATIGRAPHY

To fully appreciate the complexities we must know the component parts. Most basic to the understanding is the rock units. We will review them from oldest to youngest. (Figures 2 and 3)

Pinal schist is a quartz-sericite schist within the deposit and a quartz-chlorite-epidote schist outside the deposit. The rock is usually soft and broken and contributes to unstable slopes. A metarhyolite unit has a reported age of one billion, six hundred sixty million years ago. The bulk of the secondary sulfide mineralization is found in this unit.

Madera diorite intruded into the Pinal schist in several areas near the mine. Age of this unit is about one billion, six hundred million years.

Ruin granite intruded as batholiths into the Pinal Schist is a course grained quartz monzonite dated at one billion-four hundred twenty million years. Contact between the units to the southwest of the mine is often cited as a probable control for the later intrusions and eventually the deposit itself. Beneath the east side of the mine the contact trends more north-south.

Following a long period of erosion, the younger Pre-Cambrian quartzose units of the Apache Group were deposited. The units found at the mine are the Pioneer formation with the basal Scanlan conglomerate member and Dripping Spring quartzite with the basal Barnes conglomerate member. The Mescal limestone and Basalt units are present adjacent to the mine area, but are not extensively mineralized.

Extensive diabase intrusions, mostly as sills, were emplaced into the earlier units about one billion, one hundred forty million years ago. In the mine area there are two sills which average about five hundred feet in thickness.

Quartz rich Pinal schist and Apache Group units are generally poor hosts for primary mineralization. Hypogene grades seldom exceed 0.3 percent copper grade. Diabase was reactive to the hypogene mineralizing solutions and copper grades often exceed one percent. The bulk of the primary ore grade copper is found in the diabase.

In the immediate mine area all of the Paleozoic units have been eroded. One is left to speculate at the magnitude of the skarn deposits originally present above the present outline of the orebody.

Cretaceous intrusions are the next younger units found in the mine area. Tortilla quartz diortite dated at approximately 70 million years ago, the largest of these bodies, is found mainly to the south and west of the deposit.

Granite Mountain porphyry dated at approximately 61 million years ago has long been considered to be the causative (source of the mineralizing solutions and copper) intrusion at Ray. A porphyritic granodiorite rather than a granite, the rock is composed of oligoclase, quartz, orthoclase, and biotite-magnetite phenocrysts in an orthoclase rich matrix. At the present surface, the main mass of Granite Mountain porphyry is west of Ray in the Granite Mountain area. The Granite Mountain porphyry is found as a series of outcrops about four miles long and up to two miles wide. Outcrop pattern is sub parallel to the Pinal schist-Ruin granite contact mapped to the west. In the mine area the outcrops of Granite Mountain porphyry are mainly small and isolated.

Teapot Mountain porphyry intrudes as stocks and dikes along a northeast trend north of Ray. It is a mature porphyry characterized by large euhedral orthoclase and quartz phenocrysts. Composition is quartz monzonite.

Tertiary sedimentation began with the deposition of the Whitetail conglomerate thirty two plus million years ago. A major basin of Whitetail conglomerate exists to the west of the deposit. One unit of the Whitetail is a mudflow which had its origin at Ray and removed upwards of one hundred million tons of leach cap and secondary enrichment blanket from the Pinal schist portion of the deposit. Two economic deposits of exotic copper related to the mud flow are known. This mud flow can be traced about ten miles down the basin from Ray. In addition, drilling within the Whitetail basin has documented at least three million tons of exotic copper deposited as sub-economic native copper dispersed in sediments. This is erosion of the deposit exclusive of the mud flow.

The Apache Leap tuff is a single cooling unit that is 260 feet thick on the north side of the mine. Thickness increases to 1600 feet thick near Superior, eleven miles to the north. This tuff is rhyodacite in composition. Age of the unit is 20 million years ago.

The Big Dome member of the Gila conglomerate is named for a large dome shaped outcrop south of the mine. Clasts of Apache Leap in the conglomerate differentiate it from the Whitetail. Age dates taken from tuff beds near the town of Kearny yield dates of 17 and 14 million years ago.

The youngest Tertiary rock unit at Ray is a water lain rhyolite tuff. This light pink to brown tuff appears to interfinger with Big Dome and is shown on the map as the same unit. Similar age rocks to the west have been dated as 14 to 16 million years old.

We have defined the pit geology at the surface and here we see both the horizontal (Figure 3) and vertical directions (Figure 4). Note how the sedimentary beds west of the fault are rather steeply dipping and shallow dipping to the east of the fault. Also, note the tendency for the sills of diabase to crosscut down sequence to the east.

MINERALIZATION ZONING

This is the pattern of the primary mineralization at Ray. The horseshoe shape results from erosion and faulting on the north end of the deposit and erosion of the top of the original inverted cup shape of the deposit. The best primary grade is in the diabase sills. The hypothetical extension upward is based on my experience at Bingham where the crown of the deposit held nearly half of the copper. Note the position of the barren core where the total sulfides are low. The zone of high sulfides is asymmetrical to the west. On the east the high pyrite zone is limited to several thousand feet from the 0.3 percent copper outline in the diabase. Whereas, to the west it extends twice that distance. Work on the faulting sequence offers a plausible explanation for the westward extension (Figures 5 and 7).

This is the outline of the secondary sulfide enrichment zone. Most of the secondary enrichment is in the high sulfide zone in the Pinal schist. It is a well known fact that you must have sufficient acid to keep the copper in solution to get secondary enrichment. Thus, even where the diabase has high sulfides, the acid neutralizing capacity of the reactive minerals in the diabase is enough to use up the acid generated. Initial mining went after the high grade copper in the enriched zone. About 15 percent of the remaining reserves at Ray are secondary sulfides.

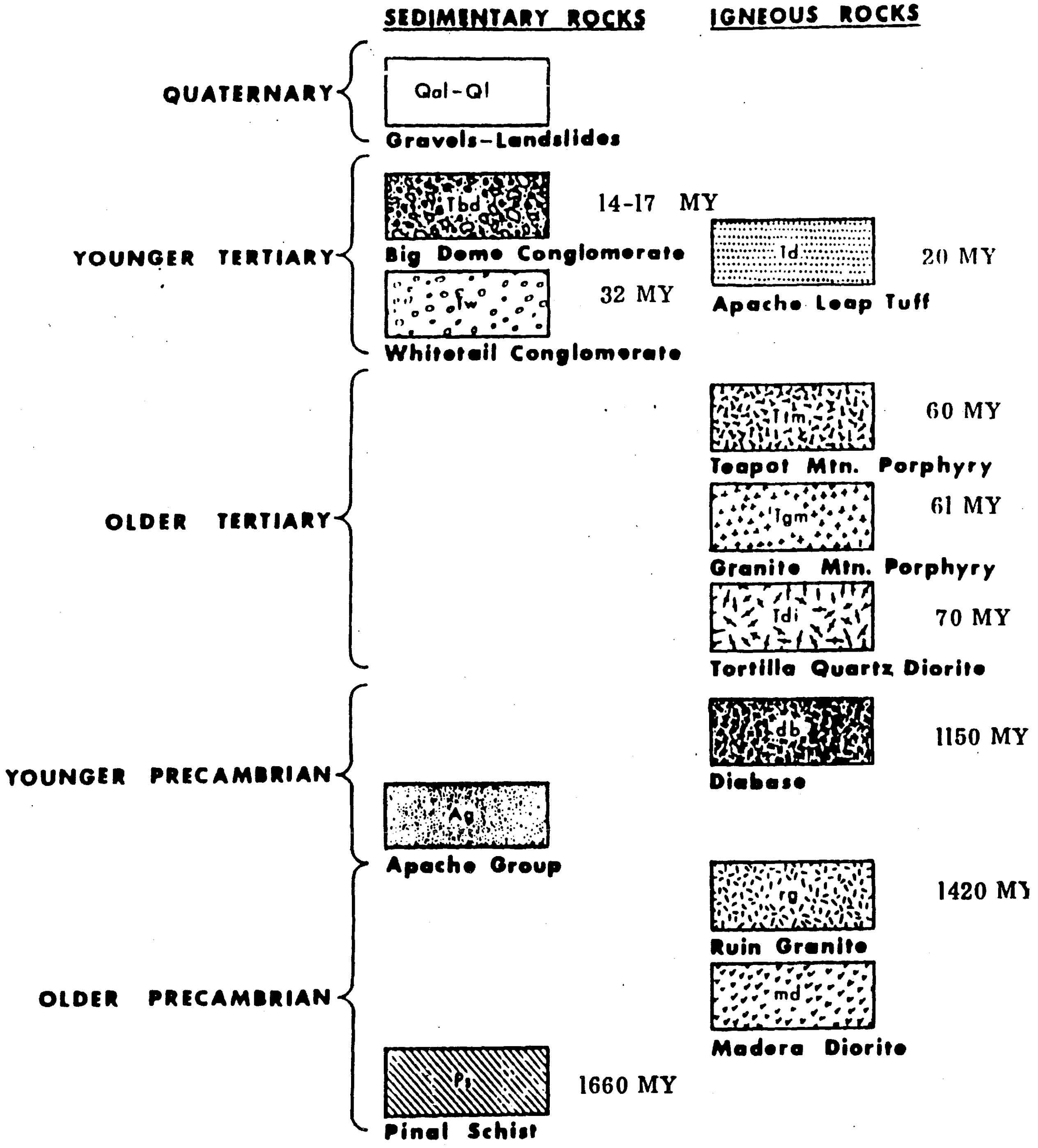


FIGURE 2
Geologic Map Key and Stratigraphy
of the Ray Mine Area

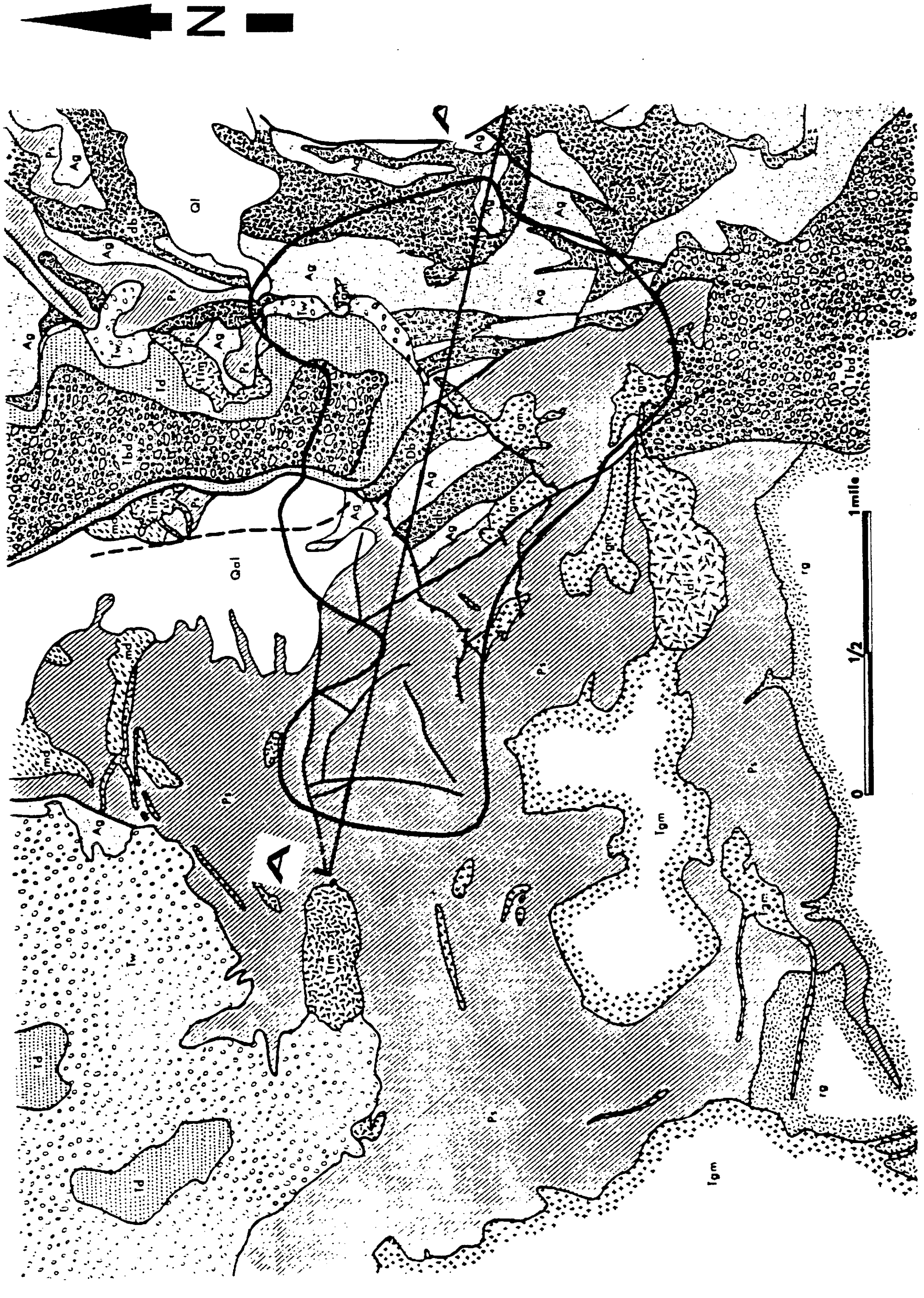


FIGURE 3
Geologic Plan Map
of the Ray Mine Area

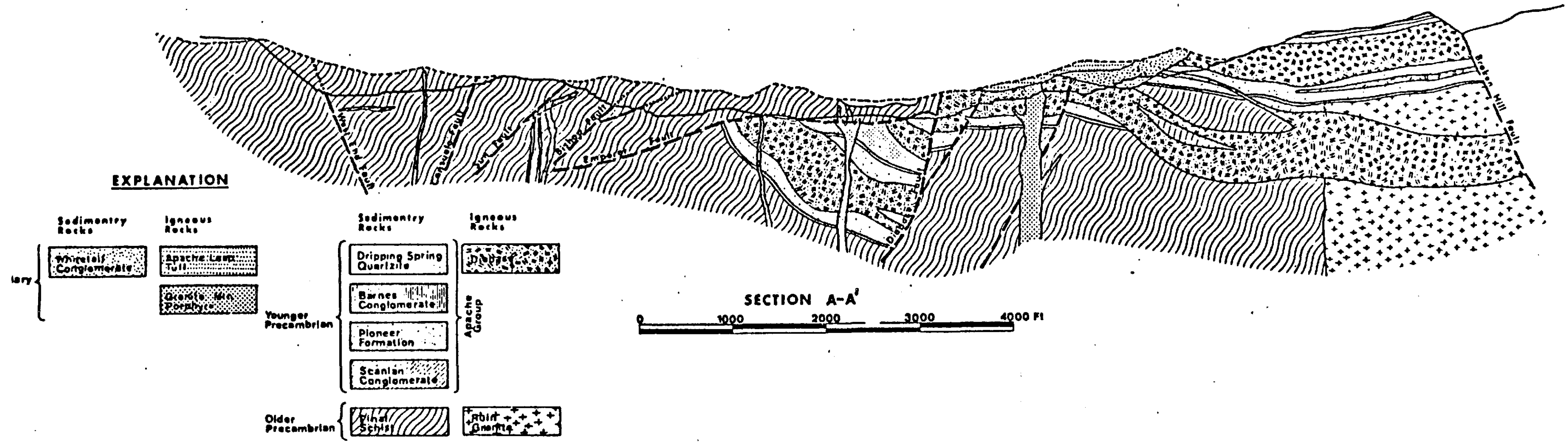


FIGURE 4
West to East
Geologic Cross Section
of the Ray Mine Area

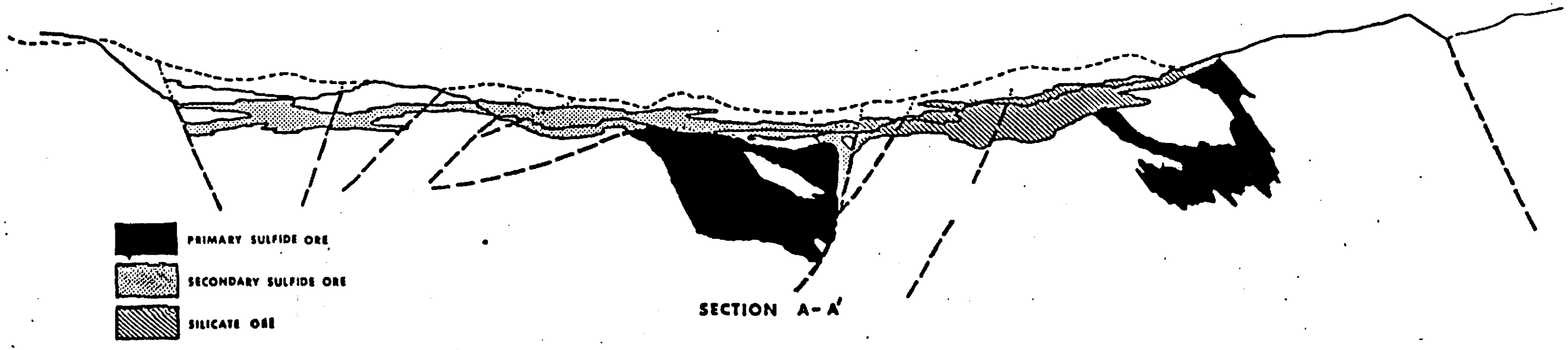


FIGURE 5
West to East
Mineral Zone Cross Section
of the Ray Mine Area

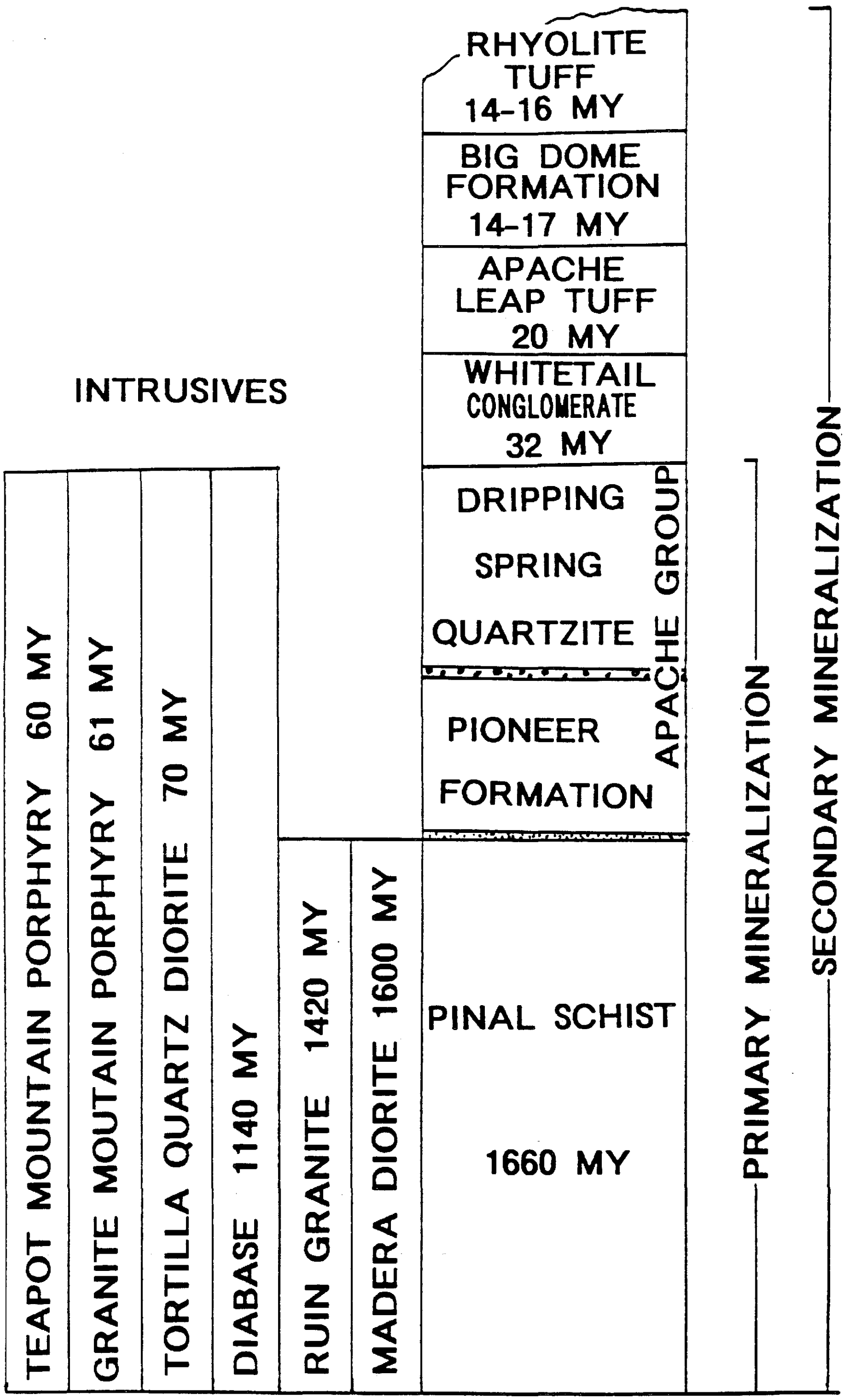


FIGURE 6
Stratigraphy and Mineralogy in the Ray Mine Area

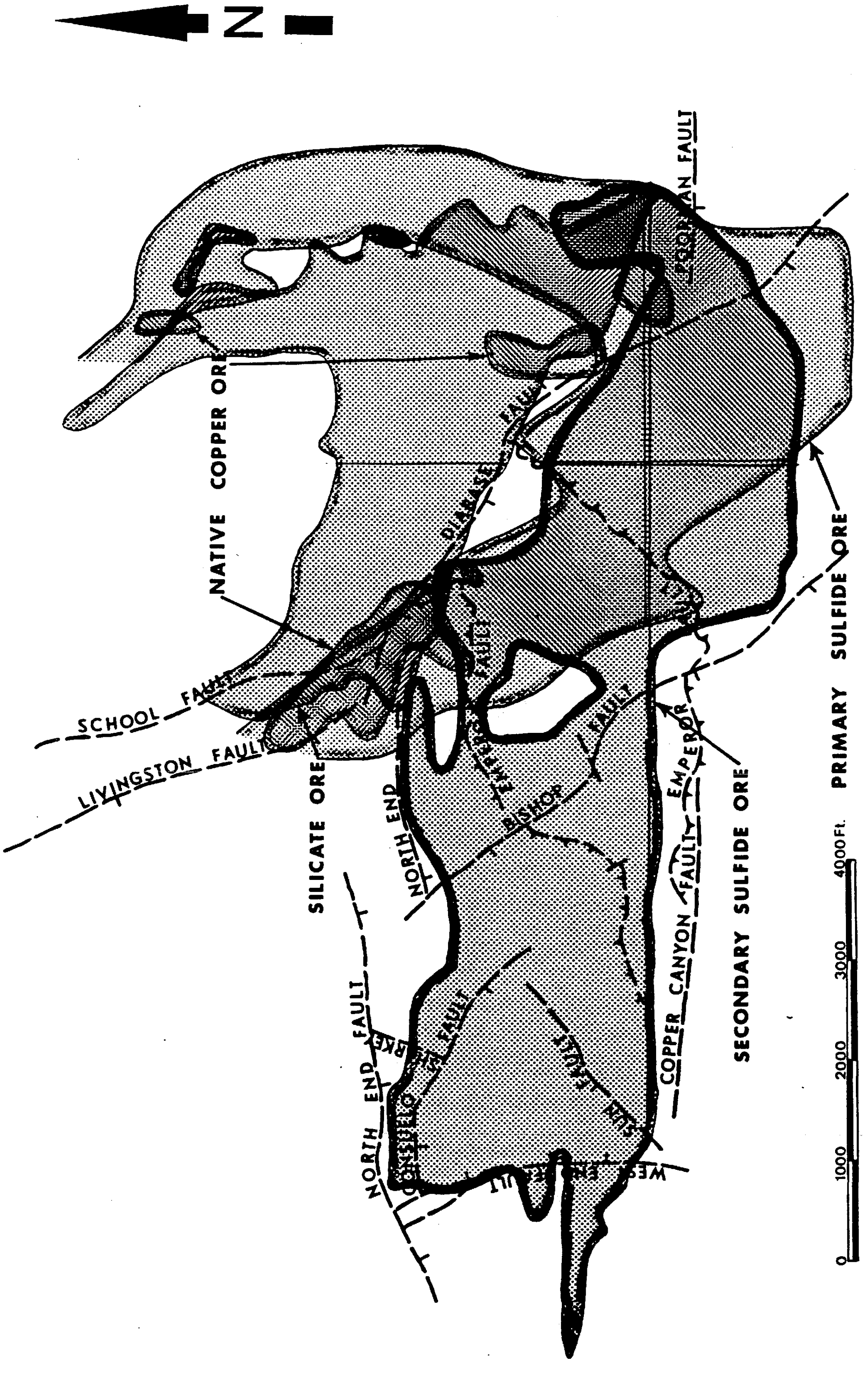


FIGURE 7
Plan Map of Mineral Zones
in the Ray Mine Area

In the barren core the acid available from oxidation of the sulfide minerals was insufficient to move the copper out of the rock. Some of the minerals in diabase will neutralize acid in rather large amounts. Where this happens secondary copper is precipitated as non-sulfide minerals. Copper in the silicate zone is present as silicates, oxides, carbonates and native. About 100 ton per day of copper is recovered from heap leaching-solvent extraction-electowinning of silicate ore.

By combining all three ore types, we see the complexity of the deposit. It takes a geologist a lot of time to adequately inform the mill of the rapid changes in mill feed. This is actually a simplified version of the deposit. Starting any new cut from the surface is a nightmare of metallurgical problems. All of the zones are usually present with the transition compressed in high sulfide or reactive rocks and expanded in low sulfide rocks.

FAULTING

Faulting has played an important role in the present outline and position of the deposit. Major faults in the district are the Diabase, Emperor, Livingstone, School, North End, West End, Broken Hill, and Copper Canyon faults. Numerous other faults are evident, but their movement is rather minor. Some of these faults exerted control on the location of the higher grade ores, particularly in the secondary enrichment areas.

The Emperor fault is a thrust which displaces the Pinal schist over the Apache Group sediments and diabase. It has been mapped cutting the Granite Mountain porphyry and in turn being cut by the porphyry. Timing of the fault is thus about 61 million years ago. The eastward dip in the pit area has lead some to postulate that it was a gravity slide off the postulated dome created by intrusion of the porphyry. The fault dips to the north at about thirty degrees at the north edge of the pit, about 15 degrees east near the center, and 20 degrees south beneath the south side. The fault terminates to the north against the North end fault and to the east against the Diabase fault.

The Livingstone fault is a thrust fault that juxtaposes Pinal Schist over all of the units exposed in the mine area. Thus, movement or at least the latest movement is post 14 million years ago. General strike is north, dip, based on drill hole intercepts,is about 45 degrees west. Surface outcrop dips are steeper. Strike of the fault is rather variable creating a sinuous outcrop pattern.

The Diabase fault appears to be a normal fault with about 800 feet of offset at the northern end of the mine and 1600 feet at the southern end. The fault terminates to the north on the North End fault, but extends south and east as the boundary fault between the tilting Dripping Spring Range and the Gila River Valley basin. At the north edge of the pit the Apache Group to the west of the fault dips about 60 degrees northeast, while on the east side of the fault the dip averages about 20 degrees southeast.

The West End fault limits the westward extension of the ore body.

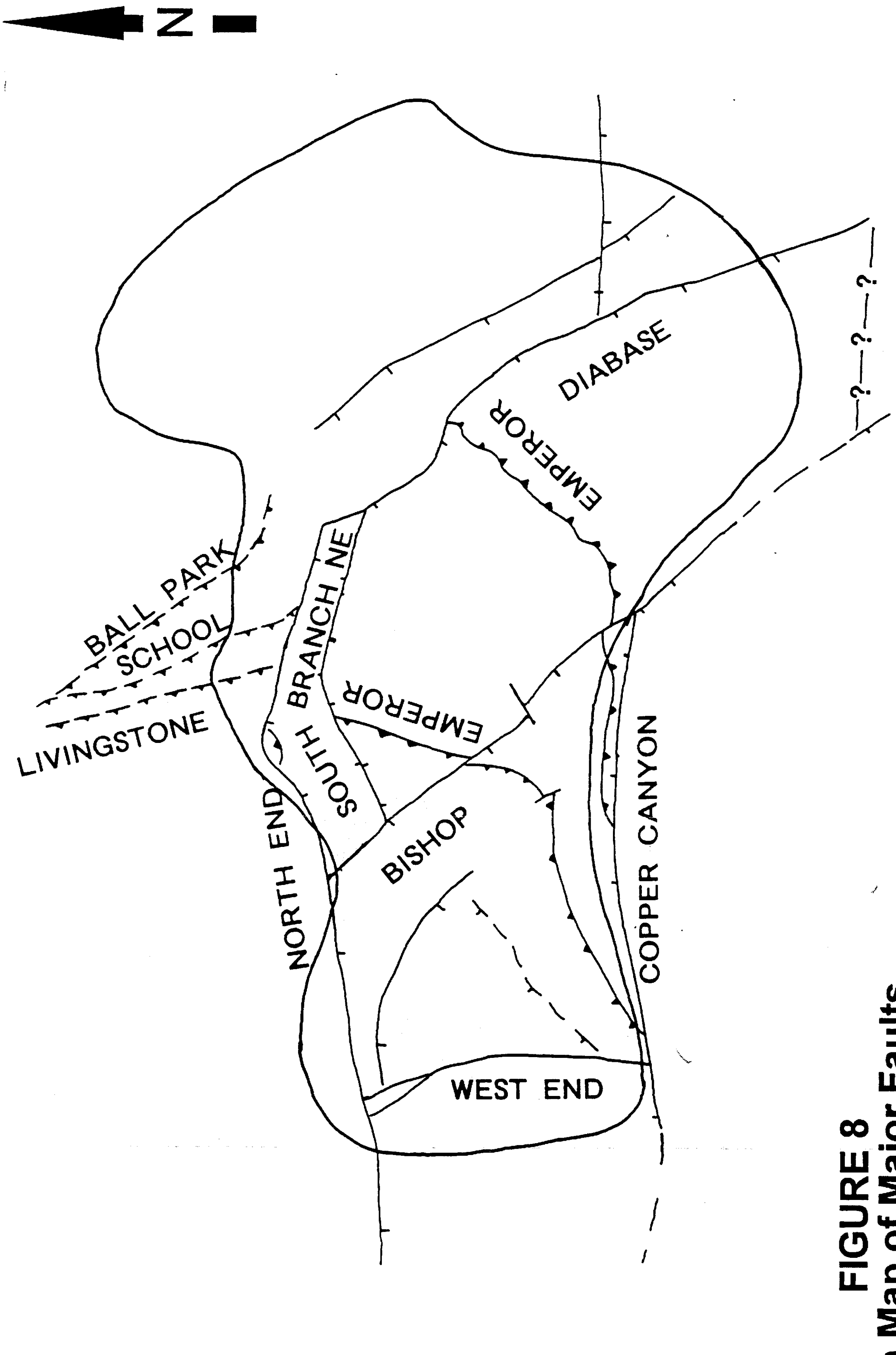


FIGURE 8
Plan Map of Major Faults in the Ray Mine Area

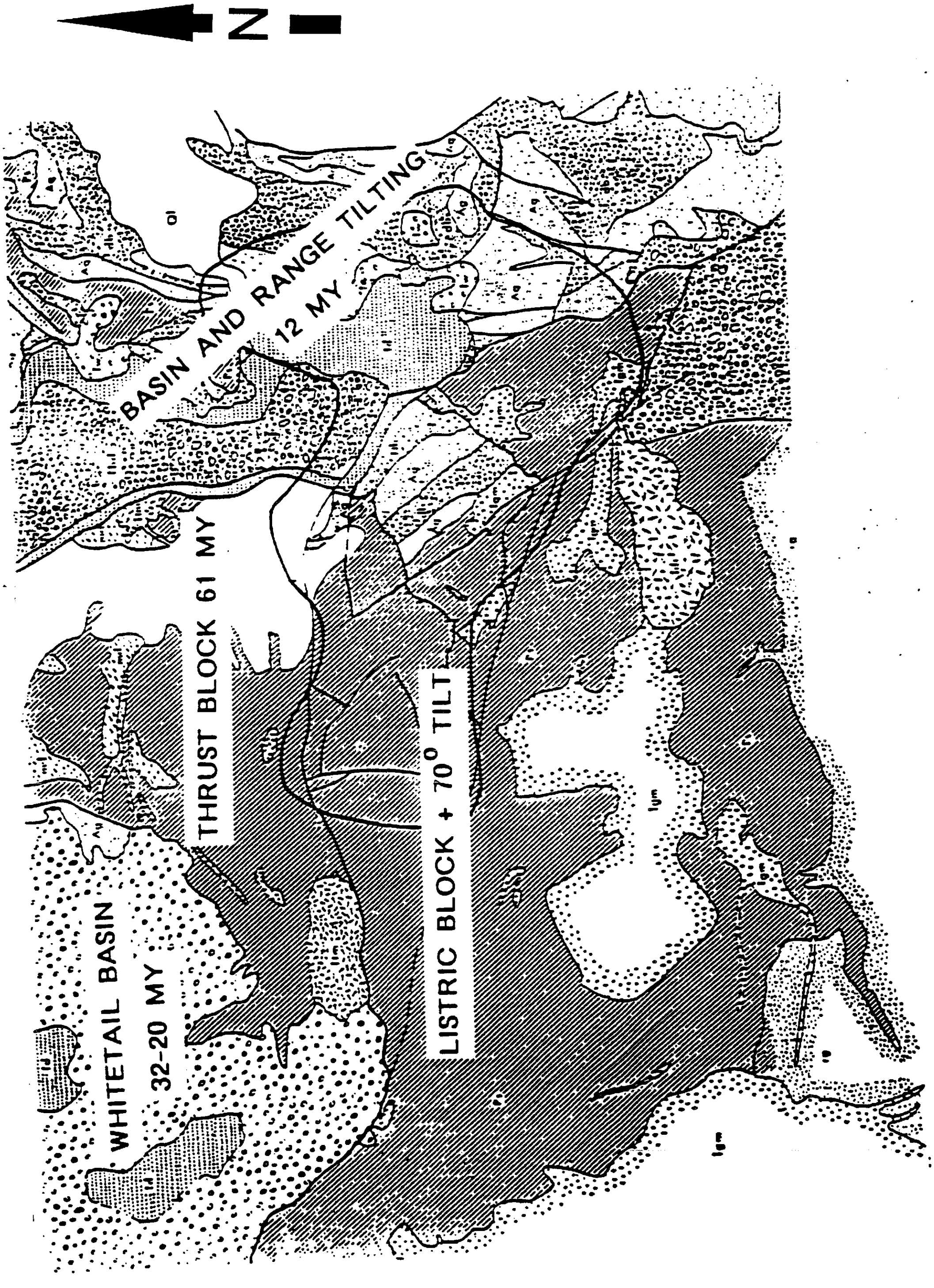


FIGURE 9
Plan Map of Structural Domains in the Ray Mine Area

West of the Livingstone fault. the North End fault cuts off the ore body and places quartz-sericite schist against quartz-chlorite schist. East of the Livingstone fault, Apache Group and diabase is placed against the Tertiary sediments.

The Copper Canyon fault places low sulfide-high chalcopyrite rock to the south against high sulfide bearing rock in the pit area (Figure 8).

Fitting these faults into the regional structure has been a complex nightmare. Current thinking is that the Livingstone and Emperor are the same fault, that the North End and Diabase faults are listric. This continues the structure of the southern Tortilla Range to the north. Rotation of the sediments west of the Diabase fault represents the tilting of the west limb of the deposit by 60 plus degrees. Thus, the west side of the deposit has been rotated from the nearly vertical limb of a normal porphyry up to nearly flat laying root of the high sulfide zone. As a result the most favorable location for secondary sulfide enrichment was given the best exposure. The age of the last movement of the Livingstone relates to the twelve million year ago event of the tilting of the Dripping Spring range. The line of least resistance for the tilting was the old break of the Livingstone thrust. However, the fault was not continuous because the Emperor block had been rotated. Adjustment took place along the North End and Diabase faults. This created a situation of not enough room for the whole block being rotated downward. Room was created by shouldering the excess rock by reverse faults known as the School and Ballpark faults. Thus, the late movement caused by tilting of the range along the Livingstone, North End, and Diabase appears as compression during an actual tension event in the evolution of the basic structural history of the region (Figure 9).

In summary, the deposit and the Emperor fault to the west of the Diabase fault is rotated about 60 degrees from the original position. Rotation is by listric movement on the Diabase and North End faults. The secondary enrichment blanket extends to the west on the rotated pyrite shell of the original deposit. The Livingstone fault is a 61 million year ago event and correlates with the Emperor thrust fault. Tilting of the Dripping Spring range renewed the movement on the Livingstone fault and since the continuation of the break was blocked by the rotation of the listric block the movement was offset on the North End and Diabase faults. This offset created a room problem which was solved by reverse faults known as the School and Ballpark faults (Figure 10).

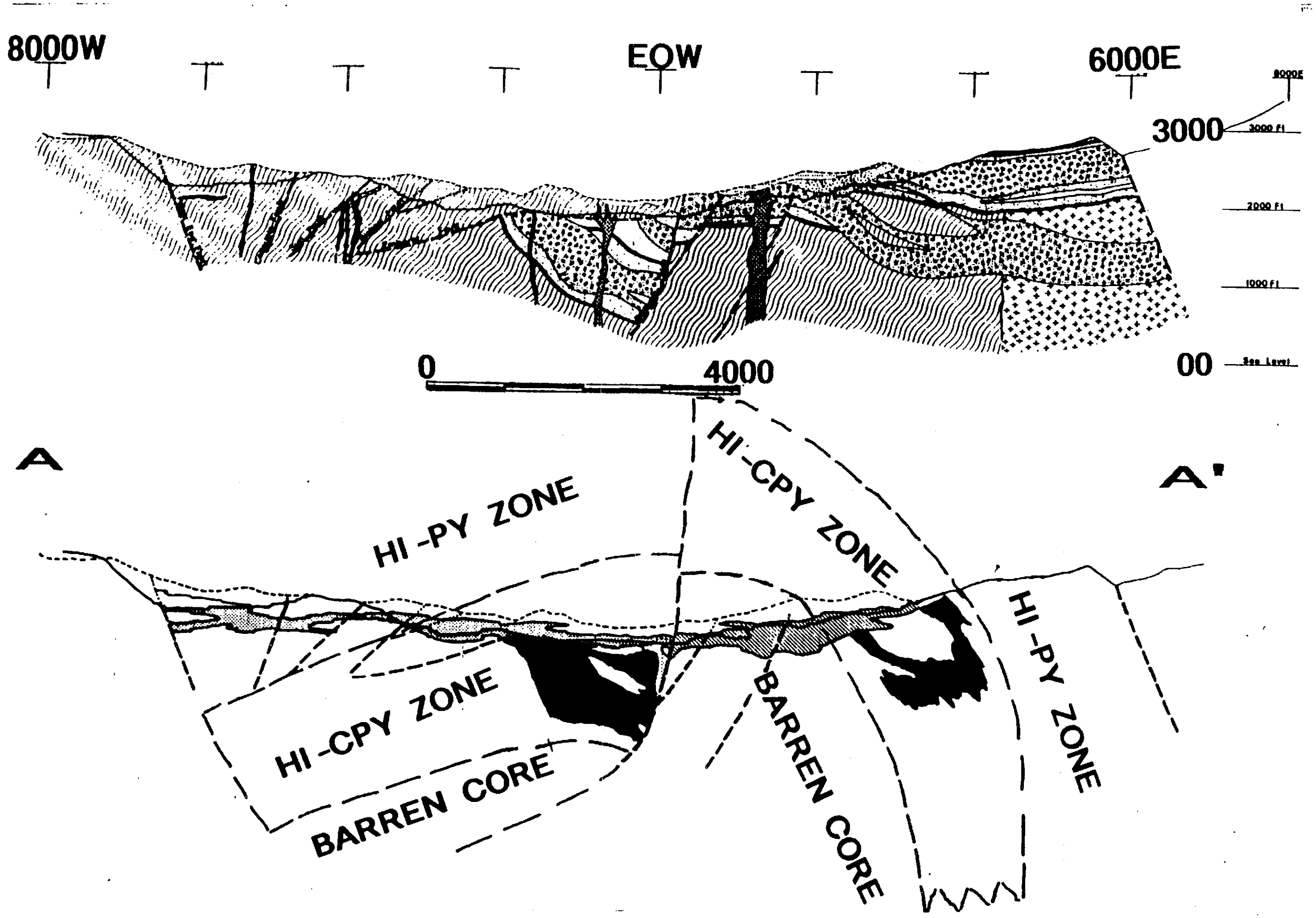


FIGURE 10
Hypothetical
Original Structure
of the Ray Deposit

REFERENCES

1. Banks, N. G. Cornwall, H. R., Silberman, M. L., Creasey, S. C., and Marvin, R. F., 1972, Chronology of Intrusion and Ore Deposition at Ray, Arziona - Part I, K-Ar ages: Econ. Geology, v. 67, p 864-878.

2. Banks, N. G., and Stuckless, J. S., 1973, Chronology of Intrusion and Ore Deposition at Ray, Arizona - Part II, Fission-track ages: Econ. Geology, v. 68, . 657-664.

3. Cornwall, R. R., Banks, N. G. and Phillips, C. H., 1971, Geologic map of the Sonora quadrangle Pinal and Gila Counties, Arizona: U. S. Geol. Survey Quad Map GQ-1201.

4. Creasey, S. C., and Kistler, R. W., 1962, Age of some copper-bearing porphyries and other igneous rocks in southeastern Arizona, in Geol. Sur. Research 1962: U. S. Geol. Survey Prof. Paper 450-D, p. D1-D5.

5. Fountain, D. S., 1981, The Ray ore Body Arizona Geological Society Field Trip (unpublished guide).

6. Krieger, M. H., Cornwall, H. R., and Banks, N. G., 1974, Big Dome Formation and revised Tertiary stratigraphy in the Ray-San Manuel area, Arizona, in U. S. Geol. Survey Bulletin 1394-A, Changes in stratigraphic nomenclature by the U. S. Geological Survey, 1972 by Cohee, G. V., and Wright, W. B., p. A54-A62.

7. Livingston, D. E. Damon, P. E., 1968, the ages of stratified Precambrian rock sequences in central Arizona and northern Sonora: Canadian Journal of Earth Sciences, Vol. 5, p. 763-772.

8. Livingston, D. E. Mauger, R. L. and Damon. P. E., 1968, Geochronology of the emplacement, enrichment, and preservation of Arizona porphyry copper deposits: Econ. Geology, v. 63, p. 30-36.

9. McDowell, F. W., 1971, K-Ar ages of igneous rocks from the western United States: Isochron/West, No. 2, p. 1-17.

10. Metz, R. A. and Rose, A. W., 1966. Geology of the Ray copper deposit, Ray, Arizona, in Titley, S. R. , and Hicks, C. L. eds., Geology of the prophyry copper deposits, southwestern North America: Tucson, University of Arizona Press, p. 177-188.

11. Phillips, C. H. Gambell, N. A., and Fountain, D. S., 1974, Hydrothermal alteration, mineralization, and zoning in the Ray Deposit: Econ. Geology, v. 69, p. 1237-1250.

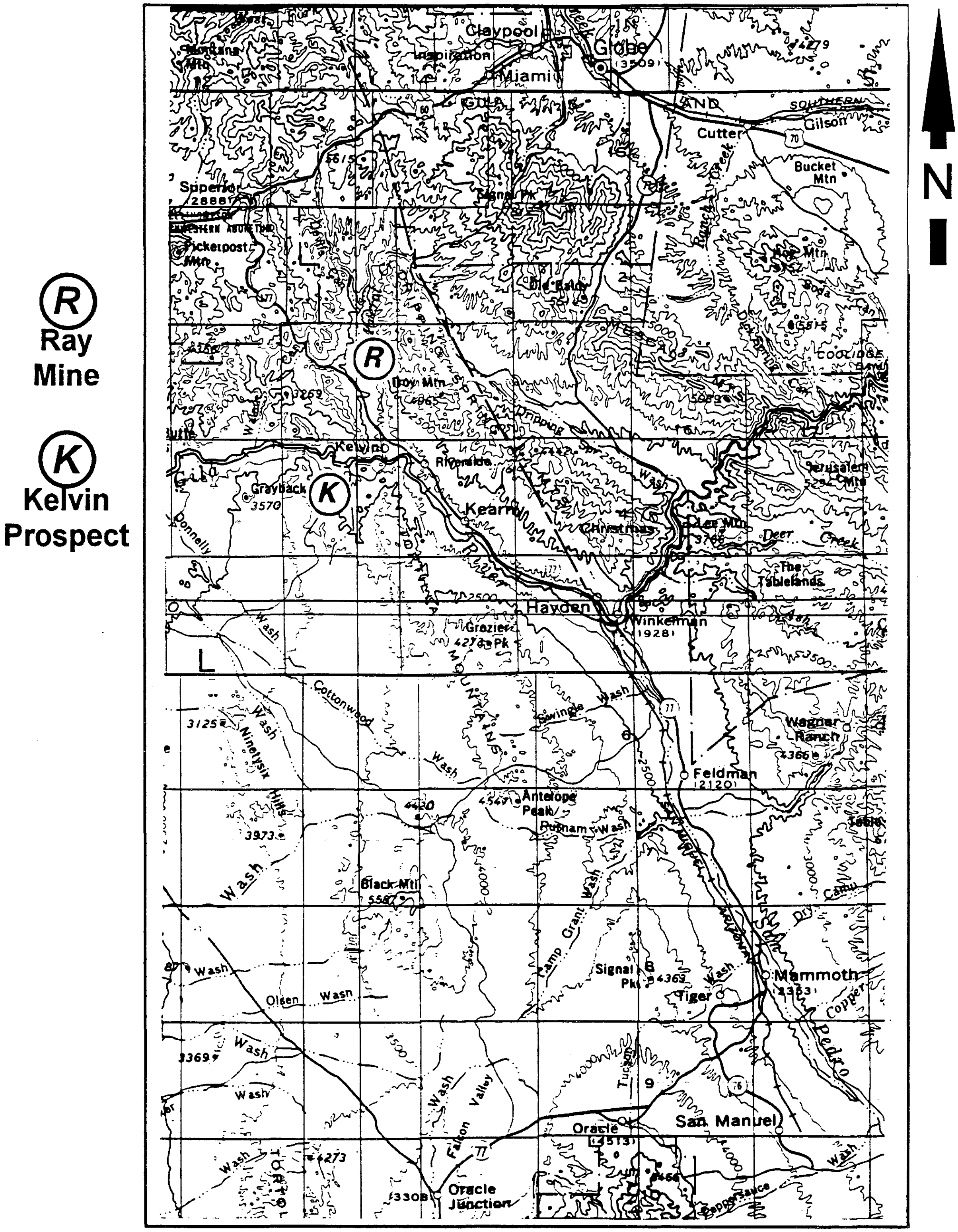


FIGURE 1

Index Map to the Ray Mine and Kelvin Prospect

adapted from U.S.G.S. Arizona Base Map

STRUCTURAL ROTATION AND STRUCTURAL COVER at the KELVIN PORPHYRY COPPER PROSPECT, PINAL COUNTY, ARIZONA

Russell M. Corn and Richard Ahern

The Kelvin porphyry copper prospect is an example of a structurally rotated system of alteration and mineralization that has been displaced by faulting and concealed beneath superimposed "structural cover". It is located in the Riverside Mining District at the north end of the Tortilla Mountains, approximately six miles south of the Ray porphyry copper deposit (Figure 1).

REGIONAL SETTING

The Tortilla Mountains and the area to the north, including parts of Ray, are in a structurally rotated terrain characterized by steep, east dipping Tertiary, Paleozoic and Precambrian sedimentary rocks overlying Precambrian granite. Diabase sills that intruded the Precambrian sedimentary rocks and the underlying granite were also rotated and are now near vertical, appearing in outcrop as though they were dikes. These sills are prominent in the granite up to 3,000 feet below the base of the overlying Apache Series but are seldom found at depths of more than 5,000 feet below that paleo-erosion surface except for occasional feeder dikes that generally trend east-west. Exposures of east-west trending Tertiary dikes intruding the granite are sub-parallel to the inferred direction of rotation.

This pattern of steeply dipping sedimentary rocks and near-vertical diabase sills in granite exposed along the east side of the Tortilla Mountains is repeated on the west side of Ripsey Wash indicating that there has been structural rotation of 60 to 90 degrees and westward movement. These rock units together with parts of the superimposed porphyry copper alteration pattern observed at Ripsey Wash have been displaced laterally along a low-angle normal fault for as much as three miles to the west relative to those exposed along the east side of the Tortilla Mountains.

KELVIN ALTERATION SYSTEM

The zoned porphyry copper alteration pattern exposed at Kelvin is a typical concentrically zoned, vertically extensive alteration system which has had the vertical axis rotated into a near-horizontal position and parts of the system displaced by low-angle faults during the period of listric faulting and structural rotation. This is similar to that described by others at San Manuel-Kalamazoo and on the west side of Ray. Alteration and mineralization effects related to the Kelvin system extend for more than 5 miles westward from the originally shallow and exterior vein and replacement mineralization at Riverside to the deep potassic alteration and molybdenum mineralization exposed in the

Rare Metals Mine area, one and one half miles west of Ripsey Wash. The ground between these two end-members approximates the trace of the rotated axis of the alteration system along which fault slices of the alteration system and associated mineralization have been identified in outcrops and in drill hole intercepts.

EXPLORATION

Exploration of the Kelvin porphyry copper system during the 1970's by Kerr-McGee, Gulf Minerals and Cities Service was based on the geologic concept of a structurally-rotated alteration system that was displaced by low-angle faults with mineralization concealed beneath subsequent slide blocks of unmineralized granite and Tertiary sedimentary rocks originating from areas outside of the alteration pattern as is schematically shown on Figure 2. Earlier Exploration by Occidental Petroleum, Kennecott, Tipperrary Resources, Cyprus Minerals and others were probably directed toward extensions of exposed mineralization and surficial alteration features based on a much simpler structural model.

EXPOSED PYRITIC ALTERATION

The pyritic-phyllic alteration exposed on top of the higher hills along the south edge of Section 12, south of the Gila River and west of Riverside occurs above propylitic altered unmineralized rocks and is interpreted as a remnant of the cylindrical zone of phyllic alteration that, after rotation, was the lower part of the now horizontal alteration system. A low-angle fault beneath the sub-horizontal zone of pyritic-phyllic alteration on top of the hills exaggerates the change to propylitic alteration at lower elevations. In this area most of the central parts of the alteration system appear to have been removed by structural disruption and erosion. The vein-replacement deposits at Riverside represent exterior mineralization related to the rotated alteration system and the Riverside breccia pipe and pyritic breccias in Section 13 to the south are interpreted as rotated exterior breccia pipes related to but outside the porphyry copper alteration center.

Supergene chalcocite mineralization is associated with the zone of pyritic-phyllic alteration on top of the hills. The chalcocite mineralization was evaluated during the 1920's and probably drilled again during the 1940's. Several additional holes were drilled in the area during the 1960's and 1970's by Kennecott, Occidental and Gulf Minerals. Data is not available, but the remnant chalcocite mineralization appears to be noncommercial and to have been partially destroyed by oxidation, leaching and erosion. The exposed pyritic alteration is terminated on the west by a high-angle fault on the west flank of the higher, phyllic altered hills. Geologic data is limited and inconclusive but the repeated segments of diabase sills that extend northward toward Ray suggest that rocks exposed west of this fault are faulted down and were displaced approximately one mile westward from equivalent diabase sills to the east.

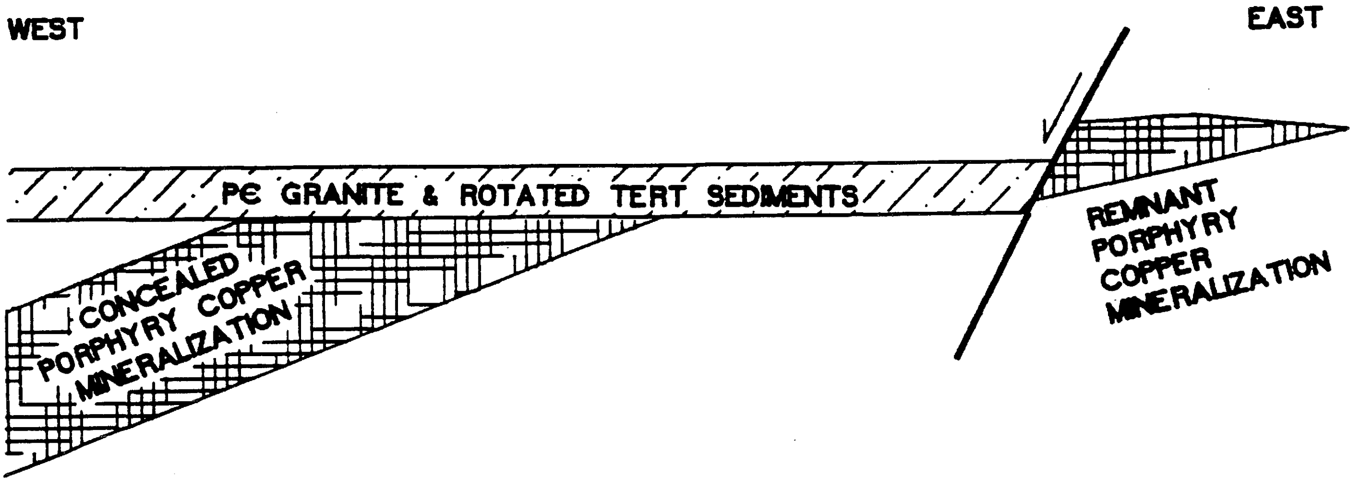
A narrow, elongate zone of pyritic-phyllic alteration is exposed west of this fault at the base of the hill north of the Florence-Kelvin road. This small area of pyritic alteration is interpreted as a segment of the outer edge of the sub-horizontal shell of pyritic-phyllic alteration. Exposures on the hill show a gradational but sharply zoned pattern of increasing intensity of alteration and mineralization, from propylitic alteration higher on the hill to phyllic alteration at the base of the hill. As shown on the accompanying section (Figure 3), this pattern of increasing intensity of alteration and copper mineralization continued with increasing depth in Kerr-McGee drill hole K-1 until terminated by a fault. An east-west trending high-angle fault that is located beneath alluvial cover, near the base of the hill, separates the phyllic alteration from unmineralized granite to the south. The propylitic altered, unmineralized granite in exposures south of the road represents a "structural cover" of fault superimposed material derived from a position exterior to the pyritic-phyllic alteration. The term "structural cover" is used here to describe extensive, displaced upper plate rocks positioned above a low-angle fault that cover and conceal underlying rock units and mineralization.

KERR-McGEE DRILLING RESULTS

Geologic relationships at Kelvin are complicated by both high-angle and low-angle faults of unknown but substantial displacement. These structures are difficult to interpret since most of the faulting involves juxtaposing different blocks of Precambrian Ruin Granite against each other and lithologic markers are scarce in the granite which hosts the alteration and mineralization. The drill holes in this area encountered alteration features and disseminated copper mineralization similar to that observed in and adjacent to Ray, San Manuel, and other porphyry copper deposits. Except for a few thin intercepts of diabase, diorite porphyry and quartz monzonite porphyry, Precambrian granite was the only rock penetrated in the Kerr-McGee drill holes. Detailed descriptions of the Kerr-McGee drill holes are available at the Arizona Geological Survey and generalized results of their drilling are illustrated on the accompanying drill hole and geologic cross-sections (Figures 3 and 4) and summarized below.

DDH K-1, located near the edge of the pyritic-phyllic alteration, is near the base of the hill just north of the Florence-Kelvin road. The drill core exhibited a continuing increase in the intensity of pyritic-phyllic alteration and increasing copper values with depth. This trend of increasing alteration intensity and mineralization terminates abruptly at a probable low-angle fault contact at a depth of 1,030 feet. Copper values above the fault were in excess of .40% copper and the 230 foot interval above the fault averaged .24% copper. Rocks beneath the fault exhibited low-sulfide mineralization and mixed weak pyritic-potassic-propylitic alteration with values of .03% to .10% copper suggestive of a deep, exterior position within a typical zoned alteration system. The mixed pyritic-potassic-propylitic alteration is characterized by fresh feldspar, chlorite, carbonate and epidote, a low total sulfide content with a pyrite to chalcopyrite ratio of less than 2 to 1 and quartz-K feldspar-magnetite-pyrite-chalcopyrite veinlets

DDH K-2, collared in an area of outcropping propylitic altered unmineralized granite south of the Florence-Kelvin road, penetrated a low-angle(?) fault at a depth of



1. Structural rotation of the PORPHYRY COPPER SYSTEM.
2. Fault displacement of the PORPHYRY COPPER SYSTEM and concealment by superimposed structurally–rotated unmineralized granite and Tertiary sedimentary rocks.

FIGURE 2
Schematic diagram illustrating the general geologic model used during exploration of the Kelvin porphyry copper system

700 feet and encountered low-sulfide copper mineralization with values of .03% to .10% copper and weak pyritic-potassic-propylitic alteration similar to that noted in the lower part of DDH K-1.

DDH K-3, located near the road but west of K-1 and K-2, penetrated the high-angle fault at a depth of 350 feet with relatively strong mineralization beneath it. Below a second fault zone at a depth of 700 feet the intensity of alteration and mineralization diminished with increasing depth in a zone of low-sulfide potassic-propylitic alteration similar to that encountered at similar depths in drill hole K-2.

STRUCTURAL COVER AND MINERALIZATION NEAR RIPSEY WASH

Exposures to the west of the area of Kerr McGee drilling, toward Ripsey wash, are dominantly propylitic altered Precambrian granite and post mineral Tertiary sedimentary rocks. The propylitic altered granite is similar to and probably part of the same structural block as the unmineralized granite noted in the upper part of hole K-2. The Tertiary units dip to the east from 20 degrees to more than 60 degrees and are underlain by shattered and brecciated granite and diabase indicative of detachment type rotation and displacement. An unusual area of Precambrian granite occurs on the west side of Ripsey Wash. It extends north from the Wooley Breccia Pipe vicinity and is bounded on the north and west by the Florence-Kelvin road. This Precambrian granite, west of and underlying the upended blocks of Tertiary sedimentary rocks, is intensely shattered and lacks the diabase sills and prominent porphyry dikes which characterize the granite elsewhere. This shattered granite appears to be a contiguous part of the same relatively thin structural slice as the adjacent rotated Tertiary units. The thickness of this structural cover is not known, but exposures of intensely brecciated granite and diabase beneath the Tertiary rocks on the east side of Ripsey Wash suggest that it may be relatively thin. In contrast, the Precambrian granite exposed north and south of this area hosts diabase sills and Tertiary dikes but is not intensely shattered. Available geologic data, in particular the near-vertical diabase sills and the gently plunging Wooley breccia Pipe, indicate structural rotation of 90 degrees for rocks on the west side of Ripsey Wash. A major north-south trending low-angle fault, evident in the Teapot Mountain quadrangle to the north, is projected beneath the structural cover along Ripsey Wash.

Scattered prospects on both sides of Ripsey Wash explore narrow east-west trending shear zones in propylitic altered granite. The narrow mineralized shear zones exhibit introduced silica, specularite and abundant pyrite with gold and supergene copper values. Several prospects have gold values of .10 to .30 OPT gold over zones several feet wide. Twin adits on the west bank of Ripsey Wash 3,000 feet south of the Florence-Kelvin road, were driven to explore oxide copper mineralization. The copper mineralization appears to be exotic, and is hosted by brecciated granite adjacent to a segment of rotated Tertiary sedimentary rocks.

The Wooley Breccia Pipe, on the west side of Ripsey Wash and south of the structural cover comprised of intensely shattered granite, is interpreted as an exterior

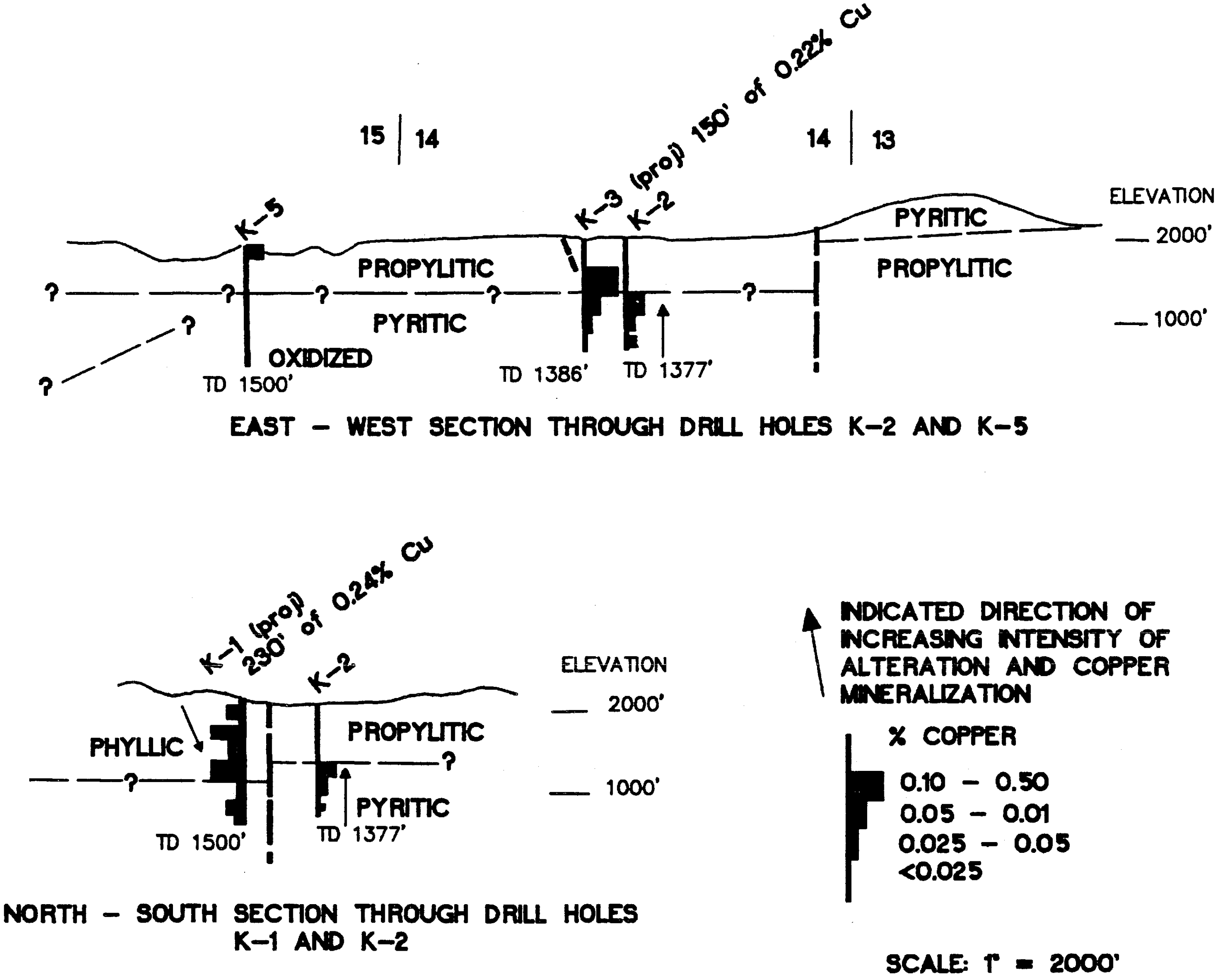
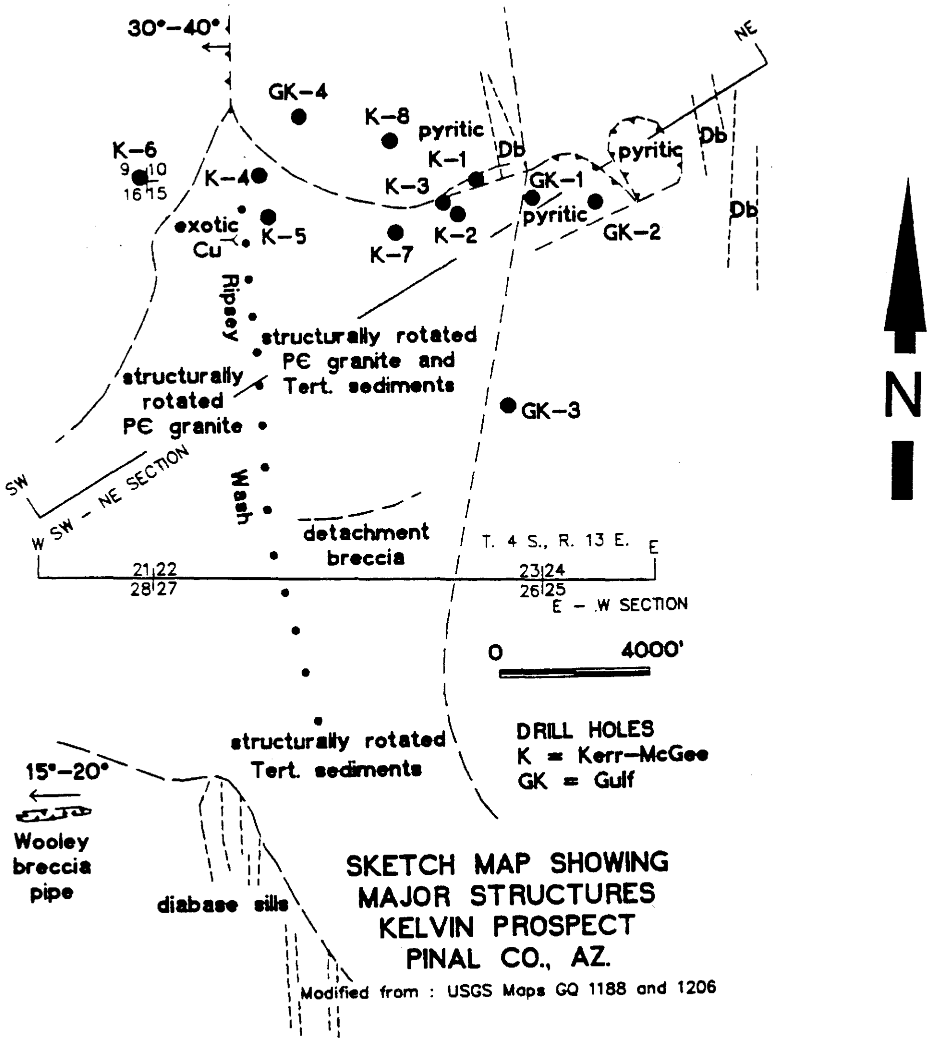
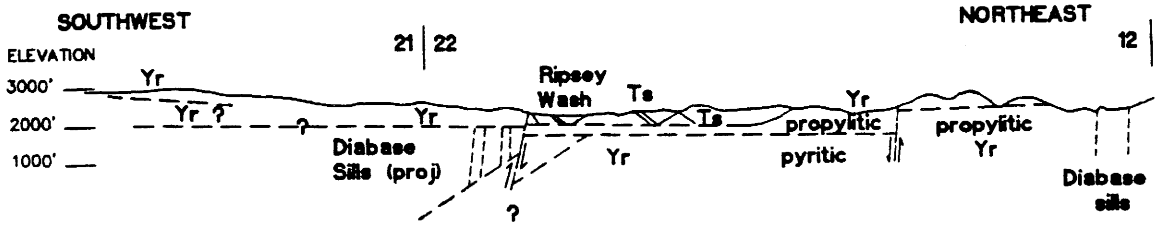


FIGURE 3
Section through drill holes at Kelvin prospect,
Pinal County, Arizona,
illustrating alteration and mineralization

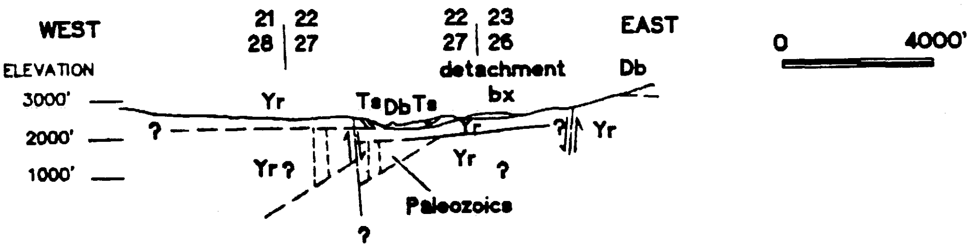


SKETCH MAP SHOWING
MAJOR STRUCTURES
KELVIN PROSPECT
PINAL CO., AZ.

Modified from : USGS Maps GQ 1188 and 1206



NORTHEAST - SOUTHWEST GEOLOGIC SECTION



EAST - WEST GEOLOGIC SECTION

FIGURE 4

Kelvin Prospect, Pinal County, Arizona

Surface geology from U.S.G.S. Map GQ 1188 and Gq 1206

breccia pipe related to the Kelvin porphyry copper center of alteration. The pipe, which is approximately 300 feet in diameter and is exposed over a distance of approximately 1,200 feet, appears to have been rotated into a nearly horizontal position by the structural rotation which accompanied the listric faulting and now plunges 15 to 20 degrees to the west. Outcrops exhibit angular fragments cemented by quartz and sulfides with a pyrite to chalcopyrite ratio of approximately 3 to 1. The rock fragments and surrounding country rock lack pervasive or disseminated pyritic alteration. The Wooley Breccia Pipe was last drilled in 1974 by ALCOA and although earlier drill data are not available, the copper content of the mineralized breccia pipe is apparently sub-economic.

The mineralized breccia pipe now trends east-west indicating structural rotation from west to east and displacement in a west-southwest direction. It is located approximately 2,500 feet west of near-vertical diabase sills on the west side of Ripsey Wash. These geologic relationships indicate that the mineralized breccia pipe probably formed beneath similar diabase sills and in proximity to and at depths equivalent to the porphyry copper alteration and mineralization exposed and drilled at the north end of the Tortilla Mountains and was later displaced approximately three miles westward to its present position west of Ripsey wash.

The Rare Metals Mine area, approximately one mile south of the Gila River and one and one half miles west of Ripsey Wash is characterized by exposed potassic alteration and very low sulfides with a high chalcopyrite to pyrite ratio and relatively high molybdenum values suggestive of a position at substantial depth in a porphyry copper alteration system. The exposed copper-molybdenum mineralization was drilled by Cyprus and Tipperary Resources in the early 1970's. Reportedly, copper values encountered in their drill holes were similar to values in surface exposures, with larger intervals averaging less than .10% copper. Cities Service drilled the area in the early 1970's and encountered significant intervals of disseminated copper mineralization at depth in three holes located in the southwest quarter of Section 9, east of the Rare Metals Mine and approximately one mile west of Ripsey Wash. These intercepts reportedly at depths of approximately 2,000 feet, averaged .40% to .50% copper and mineralization was associated with sericitic and potassic alteration and was separated from overlying propylitic altered granite by a major low angle fault.

SUMMARY

The Kelvin porphyry copper system is an example of the effects of large-scale structural rotation and associated complex displacement on low-angle and high-angle faults. It has been only partly explored and previous wide-spaced drilling was confined to the northern flank of the rotated alteration system where exposures are better. Subsurface geologic data is limited, structural relationships are not well defined and much of the area is concealed beneath an extensive, but perhaps relatively thin, structural cover of rotated Tertiary sedimentary rocks and shattered unmineralized granite. Exploration during the 1970's was based on a model of structural rotation of the alteration system with mineralization concealed beneath low-angle faults and unmineralized rocks. In spite of the geologic complexity and limited data the drilling did encounter substantial intervals of disseminated copper mineralization concealed beneath low-angle faults and unmineralized rocks.

SELECTED REFERENCES

Arizona Department of Mines and Mineral Resources files of unpublished maps and reports.

Arizona Geological Survey files of unpublished reports and drill logs.

Cornwall, H. R., Banks, N. G. and Phillips, C. A., 1971, Geologic Map of the Sonora Quadrangle, Pinal and Gila Counties, Arizona; U.S.G.S. Map GQ-1021, scale 1:2-4,000

Cornwall, H. R. and Krieger, M. H., 1975, Geologic Map of the Kearny Quadrangle, Pinal County, Arizona; U.S.G.S. Map GQ-1188, scale 1:24,000.

Cornwall, H. R. and Krieger, M. H., 1975, Geologic Map of the Grayback Quadrangle, Pinal County, Arizona; U.S.G.S. Map GQ-1206, scale 1:24,000.

Creasy, S. C., Peterson, D. W. and Gambell, N. A., 1983, Geologic Map of the Teapot Mountain Quadrangle, Pinal County, Arizona; U.S.G.S. Map GQ 1559, scale 1:24,000.

Unpublished Geologic Reports by R.M. Corn, J.P. Vroman, J. Wilkins Jr., and D.A. Wolfe for Cities Service Minerals Corp, Gulf Minerals Corp. and Kerr MeGee Corporation.

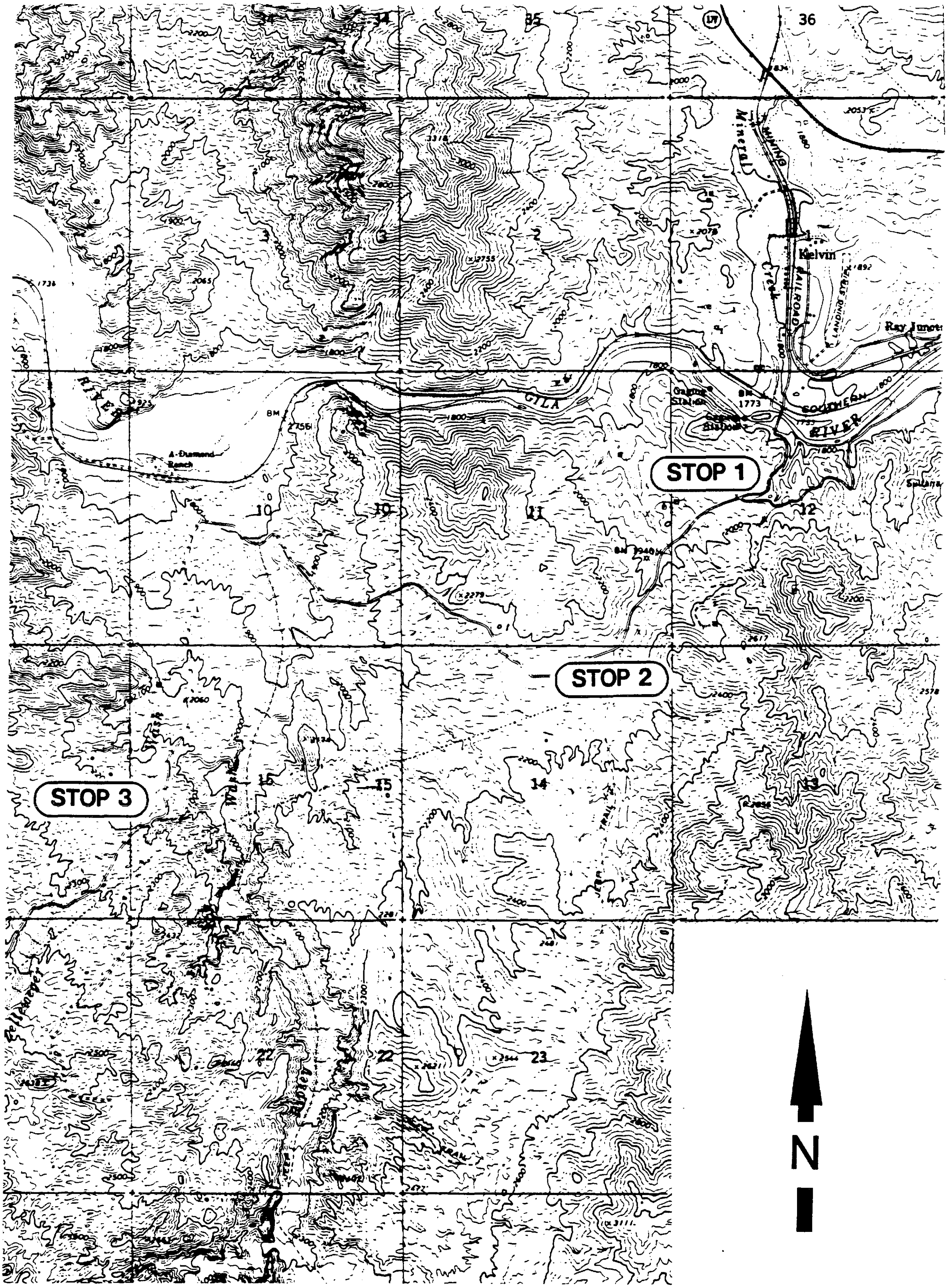


FIGURE 5

Road Stops for the Kelvin Prospect Tour

adapted from U.S.G.S. Grayback and Kearny 7.5' series maps

KELVIN PROSPECT ROAD LOG

MILEAGE
Cum. Inc.

0.0 0.0 Junction of Highway 177 and Florence-Kelvin Road, approximately four miles south of Ray. Turn south on Florence-Kelvin road along the Copper Basin railroad grade, through an area of housing at the site of Kelvin, then cross the tracks and a bridge across the Gila River.

1.7 1.7 **STOP 1** End of pavement on Florence-Kelvin Road

Exposures are of propylitic altered Precambrian granite cut by thin closely spaced carbonate stringers and narrow, siliceous, pyritic shear zones. The higher ridges to the south are capped by pyritic-phyllic alteration with associated supergene chalcocite mineralization. The pyritic-phyllic alteration is separated from the underlying propylitic altered rocks by a low angle fault and is interpreted as the outer and lower part of the structurally rotated alteration system.

2.5 0.8 **STOP 2** Kerr-McGee drill holes K-1 and K-2

Exposures of Precambrian granite on the hill north of the road exhibit a sharply zoned pattern of increasing intensity of alteration from exterior propylitic alteration higher on the hill to pyritic-phyllic alteration at the base of the hill. As shown on the accompanying section through drill holes K-1 and K-2, the intensity of alteration and copper mineralization continued to increase with increasing depth in drill hole K-1 until cut off by a low-angle fault at a depth of 1,030 feet. The exposures of shattered, weakly altered, unmineralized granite south of the road and in road cuts 100 to 200 yards west of the stop are representative of the unmineralized granite in the upper part of holes K-2 and K-3, above the low-angle fault.

Structurally rotated Tertiary sedimentary rocks are prominent along the west side of Ripsey wash several miles to the south and west and can be viewed from the road as it descends into Ripsey Wash. The drill road along the high ridge west of Ripsey Wash is in the area drilled by Cities Service, and the Rare metals Mine is in the wash to the west. These mineralized zones are situated along the margins of an apophysis of the Late Laramide Teacup granodiorite intruding Ruin granite. The contact forms much of the ridgecrest on the western skyline.

5.5 3.0 **STOP 3** Rotated Tertiary Sedimentary Rocks and Precambrian Granite

The contact of the east-dipping sedimentary units and granite is just east of the road and a short walk of 100 yards provides another good view of the tilted Tertiary units. Granite cobbles near the base of the sedimentary rocks are identical to the underlying propylitic altered, unmineralized granite and are a further indication that the shattered granite south of the Florence-Kelvin road was structurally rotated and displaced together with the adjacent Tertiary sedimentary rocks.

OPTIONAL: A short drive of several miles up Ripsey Wash, 4WD required, provides excellent views of the rotated Tertiary units and shattered Precambrian granite.