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File - "field Trips"

ARIZONA GEOLOGICAL SOCIETY

FIELD TRIP
TUCSON MOUNTAINS
27 FEBRUARY 1966

BRIEF DISCUSSION OF GEOLOGY

CONDUCTED BY
DR. E. B. MAYO
U. OF ARIZONA

DEPARTURE TIME 8:00 AM
FROM 2nd Street behind Geology Building, U of A Campus
ROUTE West via Speedway over Gates Pass and down Sahuaro Road to the first parking place from which participants will walk to stops 1 and 2, (SEE ACCOMPANYING MAP).

Stop #1 In wash north of Sahuaro Road near foot of mountains. Contact between Cat Mountain Rhyolite on north, and a rubble phase of the Tucson Mountain Chaos on south. Contact strikes about N8°W, dips about 80 degrees north. Dikelets of the "chaos matrix" penetrate the Cat Mountain Rhyolite.

What has been called the "rubble phase" of the Tucson Mountain Chaos might be merely a basal conglomerate of the Amole Arkose. It appears at many places along the Cat Mountain contact, and locally includes huge limestone blocks.

About 15 feet down-wash from the contact are Amole beds, highly disturbed, followed by purplish Recreation-type rocks. Farther down-wash, a small exposure of Amole rests with gradational(?) contact on Recreation Red Beds.

Stop #2 Two hundred yards(+) south of a big Silver Lily dike. Approaching limestone block through Cat Mountain Rhyolite, small masses of the "chaos rubble" are seen, then highly disturbed, bedded Amole. The edges of the limestone exposure are rubbly, as though partially disaggregated. West of the limestone, an exposure shows very steep flow structure in the Cat Mountain Rhyolite. Coming down wash to west of this exposure, the Cat Mountain Rhyolite contact is covered, but the last small outcrop reveals steep dips.

RETURN TO CARS AND PROCEED TO JUAN SANTA CRUZ PICNIC AREA.

Stop #3 First colorful outcrop in Juan Santa Cruz Wash. Shows apparent mixing of red siltstone with coarser, purplish clastics. Chips of red siltstone are on top of the outcrop. Laminae in bank dip away from coarse rubble and are overlain by pinkish sandstone.

Stop #4 Second outcrop. Mixing of coarse and fine-grained materials.

Stop #5 Zone of disturbance on bend in wash. On the north side, sandstone intrudes(?) red beds. There are many red chips in the purple sandstone below. Twenty feet down wash, on the north side, purplish rubble breaks upward through red beds along a fissure(?). Similar phenomena appear on the south side, where coarse clastics show steep dips.

Stop #6 In "Amphitheatre" below. "Fluidized rhyolite boulder" in red beds. The red siltstone appears to have worked its way into the "boulder" as it disintegrated.

Stop #7 "Eruptive fissure." Climb back on north side to view fissure to south. Red bed layer to west rises eastward into fissure, then appears as a block in the fissure zone. Red bed layer up-wash, to the east, should be below level of wash at this place. Before leaving position on bank, notice steep red beds intruded(?) by purplish rubble. On south side notice that the red bed seems to grade eastward through laminated sandstone into the fissure filling, yet the lamination, which is flat, can be traced into the fissure filling, some of which appears to have welled upward. To the right (west) the red bed is overlain by a well-stratified light gray rock(tuff?). Climb up fissure on south side of wash. The surface trace of the fissure is marked by breccia, under which is the "tuff." Steeply-dipping red bed wisps appear along the fissure zone to the crest.

Stop #8 Farther down wash and under the red bed. The red bed seems to have no definite lower contact, and it may have been lifted by the underlying rubble. Notice the many large clasts in the red bed. Trace the red bed up out of the wash to the south. From its probable trace, it must have been lifted by something below. The dip becomes reversed, from westerly to eastwardly. Uplift seems to be corroborated by steep eastward dip in exposures below the main red layer. Were the conformable sandstones deposited with the red beds, or did they lift and intrude the red beds?

Stop #9 Around sharp bend in wash, at the north end of a large quartzite lens. Structural discordances, locally bordered by rubble, appear within the quartzite. The overall structure seems to be anticlinal, but some inner portions seem to have welled upward across outer ones. Some of the quartzite shows a peculiar mottling, possibly associated with destruction of lamination. There is a small porphyry mass on the east side, and the red beds east of the porphyry are probably a lower member than we have seen before.

Stop #10 At south end of quartzite lens. Lamination converges to a point at end of lens. Laminae to the south swerve around the lens. Behind them is a larger mass of porphyry.

Stop #11 On east side of porphyry, small sedimentary dikes.

Stop #12 At dam. "Intrusive breccia" on contact between andesite and quartzite has rounded clasts. Is this comparable to the "rubble phase" of the Tucson Mountain Chaos?

Stop #13 Near west contact of the porphyry, on a flat surface, little pipes of the porphyry have risen into pinkish-brown sandstone. Other contact details are exposed near-by.

Stop #14 At small intrusion on northwest side of main mass. Near south contact, northwest-striking lamination in quartzite is cut off abruptly near the intrusive contact by very faintly laminated quartzite that parallels the contact. In the northeast wall a "fissure of fumarolic action" has laminae striking N70E across laminae in quartzite that trend about N25W. Is this an indication of the way in which cracks were widened for intrusion from below?

Stop #15 On trail in gap between north and middle peaks in Piedmontite Hills. The ignimbrite (equivalent to the Car Mountain Rhyolite?) has intruded with steep contacts the volcanic rocks. To the south the trace of the contact of ignimbrite with volcanics can be vaguely seen. In the hill on the right, flatly-dipping ignimbrite is overlain by volcanic rocks.

Stop #16 On hill west of central peak, and above the ignimbrite. A band of red beds on the eastern slope is upended and intruded by purplish-red fragmental volcanics. On the north slope also the coarser clastics appear to intrude the red beds. Near the top, the coarse clastic volcanics "stand on end" as though pushed up from below. Some of this material is pinkish as though from admixture with underlying red beds. Stages of intrusion and mixing can be seen below. Walk down around west edge of coarse clastics, and around south end. Clastics appear to occupy a SE-plunging trough, down which they flowed? Or perhaps they welled up along a SE-trending fissure? Observe the strong disturbance of the red beds and intermixture with coarser clastics at SE end of outcrop. Walk up along east side of outcrop. Did the coarse rubble flow SE, down a trough; did it rise along a fissure and spread sidewise; or did both actions take place? The hot, intrusive ignimbrite was probably not far below this level.

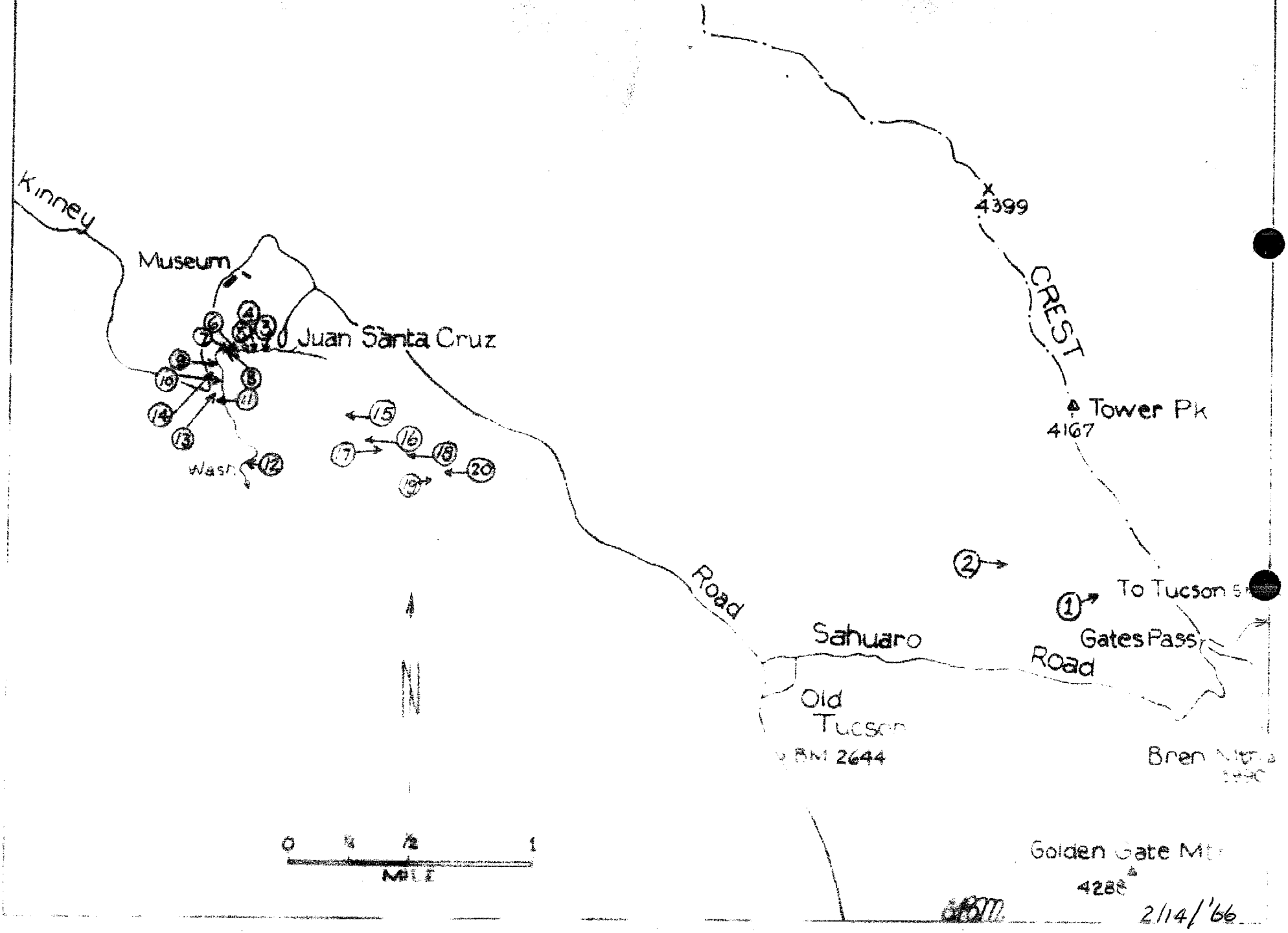
Stop #17 On trail on south slope of the middle peak, rubble seems to have lifted the stratified volcanics.

Stop #18 On top of south peak, steeply-dipping red streaks suggest steep upwelling.

Stop #19 Small pipe of ignimbrite on trail.

Stop #20 Off trail to NE, and above #19. Mass of rubble appears to have risen steeply. Strata dip steeply off it to the east. Walk around eastern base of outcrop. Here, again, are disturbed red beds, mixed with coarser debris.

SKETCH MAP OF PART OF THE TUCSON MOUNTAINS: LOCATIONS OF FIELD TRIP STOPS, FEBRUARY 27, 1966.



W. L. K.

JUN 1 1973

AMERICAN SMELTING AND REFINING COMPANY
Tucson Arizona

May 31, 1973

file

Field Trip - FTG
Quebec - Ontario

Memorandum to: W. L. Kurtz

From: F. T. Graybeal

University of Arizona
Economic Geology Field Trip
to Quebec-Ontario
May 14-23, 1973

INTRODUCTION

This trip was arranged by J. M. Guilbert of the Univ. of Arizona with considerable assistance from R. W. Hodder of the Univ. of W. Ontario. The cost of $600 per industry representative was believed more than justified by the wide variety of geology seen and the outside talent assembled for specific areas. Rock specimens from the areas and mines of greatest interest, along with maps and guidebooks, are available for those interested. I will try to summarize the high points of the tour and will append discussions of the various mines visited.

SUDBURY AREA

One day on the surface with R. W. Hutchinson (U. of W.O.) and K. Card and D. Innes (Ontario Dept. of Mines) and one-half day underground at Inco's Coleman mine (North Range) were spent in the Sudbury district. Although the astrobleme theory was widely discussed, the majority of local geologists appear somewhat skeptical. Hutchinson and Card have published a short paper suggesting an alternative method of origin. They note that the upward sequence of norite - micropegmatite - Onaping tuff of the Sudbury irruptive is very similar to the typical Archean volcanic cycle which starts with mafic volcanism and ends with extensive felsic pyroclastic activity. They point out that the sizeable sulfide deposits (up to 50 million tons of 1.4% Cu, 4% Zn with minor Pb-Ag-Au in sideritic iron formation) which occur at the top of the Onaping are quite similar to the massive sulfide deposits which occur at the top of the felsic pyroclastic domes such as those at Noranda. They suggest that the irruptive is simply a deeply eroded volcanic pile. Although they might go along with an astrobleme triggering mechanism for the emplacement of the irruptive, they point out that the location of the Sudbury area at the junction of 3 regional structures is somewhat coincidental. The details of the Coleman mine are appended.

COBALT AREA

One day was spent on the surface and underground at the Silverfields mine, one of two remaining producers in the camp. Their production is

200 tpd of ore averaging 20 oz. Ag. Concentrates average 4000 oz. Ag, 6-8% Ni+Co, and 5% chalcopyrite, and are sent to Asarco-El Paso, the only smelter which will accept such ore. The veins are 1/8-6" wide and consist of native silver and a bewildering assemblage of Co-Ag-Ni-As-Sb-S minerals in a pinkish calcite gangue. The veins often assay as high as 11,000 oz. Ag and stope widths up to 40 ft. wide are cut where several parallel veins are encountered. The host rocks are conglomerate (tillite) and quartzite of the Gowganda formation.

SHERMAN AND ADAMS MINES

Both these mines are typical Archean banded magnetite-quartz-red chert iron formations of the Algoman type. They are located south and north of Cobalt, respectively, and tend to lie along the contact between underlying rhyolite pyroclastic and overlying mafic andesitic rocks. Minor amounts of banded sulfides also occur in the ore.

NORANDA DISTRICT

All significant mines and most of the other deposits in the Noranda district occur at the top of rhyolite pyroclastic deposits and below overlying andesitic rocks. The sequence of andesite $\longrightarrow$ rhyolite is thought to represent a single cycle of volcanism which, in some cycles, was culminated with a period of exhalative activity resulting in the formation of sulfide ore deposits. As such, the recognition of these rocks in the field is an important ore guide.

Although the separation of andesite and rhyolite flows should be a simple matter, in fact they are almost indistinguishable to a newcomer. Both are greenish-gray and very fine grained in spite of the fact that regional metamorphic effects are very slight (contrary to earlier thought). The rhyolites tend to have conchoidal fracture, are strongly and irregularly jointed, have badly contorted cherty flow(?) bands, ring under the hammer, and yield a white powder when the weathered surface is scratched. Individual rhyolite flows, 300 ft. thick, have been traced for 30,000 ft. (exposures in this area are excellent), and, according to Colen Spence (Rio Tinto geologist who led the Noranda tour), are definitely single flows regardless of experimental work which suggests that siliceous rocks don't flow. Some or all of the flows are thought to be subaqueous. The andesites are pillowed, softer and more massive than the rhyolites, and tend to weather brownish as compared to the grayish-weathering rhyolites. The SiO_2 content of the andesites is generally below 60%, and in the rhyolites exceeds 65%.

Commonly, but not always, a thin (1/2-6"), gray, thin-bedded chert occurs between the rhyolite and overlying andesite, particularly along a mineralized horizon. This rock is often referred to in the literature as a tuff or cherty tuffite. Pyrite is generally an accessory mineral and this rock is thought by some to be an exhalative deposit representing the pyrite-chert facies of an Algoman iron formation. Spence thinks some of the chert

shows graded bedding and, therefore, is not exhalative. Base metals are abundant in the chert within 50-100 ft. of a massive sulfide lens in the Millenbach mine; however, the extremely variable base metal content of the chert on a district-wide basis has rendered geochemical sampling of this rock singularly unsuccessful.

Evidence given in the appended paper on the Vanze mine and also available from other mines in the district points conclusively to a volcanic-exhalative, syngenetic origin for these ore deposits. All of the deposits are underlain by a pipe-like zone of massive chlorite alteration in rhyolite which also contains stringers of chalcopyrite locally abundant enough to constitute ore. The massive sulfide lens lies on top of the chlorite (or alteration) pipe and is commonly zoned with chalcopyrite at the base (and in the center) overlain (and surrounded) by massive sphalerite. Recoverable amounts of silver and gold are common and lead is rare. Thin zones of chert lie under, within, but most commonly on top of the massive sulfides. The Delbridge mine was reported to have been found by tracing the chert lens in the direction of thickening.

Many of the deposits lie at or near the crest of local rhyolite domes. In fact, the Vauze, Norbec, Millenbach, and possibly others were discovered by constructing isopach maps of the rhyolite which formed the stratigraphic footwall of the favorable horizon and concentrating drilling near the tops of these features.

Associated with the domes are two types of pyroclastic breccias. One, which is well-exposed near the Quemont mine, has angular fragments of many different rock types in a fine-grained quartz-chlorite matrix and is interpreted as forming during a vent-cleaning eruption related to deposition of the uppermost of the rhyolite section. The second type of breccia is similar to the first, except that the fragments are only those in the uppermost portion of the vent. Breccias of the second type are intimately associated with ore deposition and probably resulted from minor pyroclastic explosions during the hot spring activity which occurred during ore deposition. The eruptions of pyroclastic material and ore-forming hot spring activity are thought to have occurred under water, although proof is somewhat lacking. Exposures of the West MacDonald deposit (4% Zn, no Cu, and no chlorite) show flowage features suggestive of slumping of a mud and even exhibit pillow-like structures.

The deposits closest to the Lake Dufault granodiorite have developed a cordierite-anthophyllite-biotite hornfels within the alteration pipes. This feature, formerly thought to be an alteration phenomenon associated with ore deposition, is now known to result from the coincidence of the specific chemical composition of the alteration pipes and the contact metamorphic aureole set up around the granodiorite. Although the hornfels is post-ore, it is still used as an ore guide, due to its occurrence only within the alteration pipes under the massive sulfide ores.

All but one of the deposits in the Noranda camp are overlain by fresh andesite. The exception is the Amulet A deposit, a small zone which occurs in an overlying andesite. It is attributed to a continuation of the volcanic exhalative activity after deposition of the overlying andesite. It occurs directly above the much larger Amulet C orebody.

Ore guides in the district in order of decreasing importance are 1) the 3rd volcanic cycle, locally referred to as the mine series, 2) the upper contact of the rhyolite in a given cycle, 3) rhyolite domes, 4) alteration pipes, and 5) mineralized cherty, bedded tuffs. Exploration in the district, although difficult because of the blind nature of the ore deposits, is continuing primarily by deep drilling (to 5000 ft.) of the favorable horizons. For instance, it took 134 holes to find the Norbec, although it was a relatively shallow occurrence.

KIRKLAND LAKE - LARDER LAKE

The geology and stratigraphic interpretations of this area are succinctly discussed by R. H. Ridler in a paper in the Univ. of Ariz. guidebook. Ridler also guided our group for this portion of the field trip. Although the structure and stratigraphy of this area is complex, Ridler feels he is able to locate the central portions of several large strato-volcanoes primarily based on the lateral variation of fine-grained sediments into coarse unsorted polymict conglomerates containing mostly volcanic clasts. Flanking these volcanoes are extensive deposits of stratigraphically correlative oxide and carbonate iron formation facies.

The carbonate facies -- primarily quartz, ankerite, and micas -- is of particular interest because it contains up to 2000 ppb Au, as compared to the enclosing sediments and volcanics which contain less than 1 ppb Au. This carbonate rock, normally mapped as faulted quartz-ankerite schist, is thought by Ridler to be an exhalative volcanic sediment rich in gold and low in iron and can be traced for 10-20 miles along strike. Mariposite, the Cr-rich muscovite, is locally abundant as well. Although many of the mines in this carbonate rock did have gold-quartz veins, thought to represent minor remobilization of material in the carbonate iron formation, some of the largest stopes were within the carbonate and had assay boundaries. Although the carbonate iron formation is not well banded, Redler points out that the occurrence of massive sulfides and massive chert indicate that banding is not a prerequisite for an exhalative origin.

Close to the volcanic centers Ridler accepts without reservation an epigenetic origin for the gold, particularly the Kirkland Lake area where the ores occur in a fault zone within a syenite. Although the ores in the Kirkland Lake-Larder Lake area are in or related to an alkalic igneous province, Ridler feels that the relationship is due to the fact that the rocks at the culmination of the volcanic cycle happened to be alkalic, and that the relationship of gold to alkaline rocks is not a chemical prerequisite

to ore formation. This concept of an exhalative origin for these gold deposits is an important addition to ore deposit theory and, in addition, may have exploration significance in that the gold-bearing horizon can be repeated by folding many times rather than dying out forever with depth.

PORCUPINE DISTRICT

Our group was split up in this area with half at the Dome mine and half at the MacIntyre mine. The Dome has produced, since 1911, 9.7 million oz. Au and 2.5 million oz. Ag. Production is 2000 tpd with costs of $12.00/ton. The details of the geology are included in the guidebook. Of more general interest was the so-called "Highly Altered" rock which either contains or is very close to the gold veins. This is a quartz-ankerite schist with irregular zones of mariposite. The similarity between this rock, the outcrops of the carbonate iron formation visited with Ridler, and identical-sounding occurrences in the Kerr Addison mine suggest a similar origin.

The group at the MacIntyre (I was not) saw only the "porphyry copper" zone and apparently were not convinced. To a man they thought that the copper occurred in a quartz-sericite schist (altered andesite?) not in the Pearl Lake porphyry. The samples they collected showed bedded disseminations of pyrite, chalcopyrite, and bornite and the suggestion was made that it, too, might have exhalative affinities. A recently recognized, although somewhat debated, extrusive equivalent of the Pearl Lake porphyry was seen on a surface tour and looked surprisingly like the dacite at Silver Bell.

KIDD CREEK

This place is in a class by itself. Tonnage was not given, although 100 million tons is often quoted and the ore is reported to have been cut in drill core at 3000 ft. depth. Grades were cited as "at least" 1.8% Cu, 8% Zn, 3 oz. Ag., and recoverable Cd, Au, Sn, roughly comparable with values given in the Canadian Mines Handbook.

There are two ore lenses as described in the brief paper in the guidebook. The ore is capped with a pyroclastic rhyolite which is underlain successively by red chert with bedded pyrite (iron formation), massive graphite with angular fragments and rounded pebbles of pyrite and sphalerite, massive pyrite-sphalerite, massive chalcopyrite, and at the bottom a chalcopyrite stringer zone with abundant sericite and minor chlorite. The entire section was spectacularly exposed across one bench during our tour.

SPINIFEX

Spinifex is a textural term used to describe bladed intergrowths of olivine crystals which sometimes reach lengths of 12 inches. The area we visited is described in detail in the March 1973 issue of the G.S.A. Bull. Spinifex occurs in rocks which can be conclusively shown to be ultramafic lava flows. The Alexo, Texmont, and possibly Thompson nickel deposits in

the Canadian shield have recently been shown to have associated spinifex-bearing rocks. Spinifex has also been reported from W. Australia and a nickel prospect is currently being drilled in S. Rhodesia which contains disseminated and massive zones of pentlandite at the base of spinifex-textured ultramafic lava flows. Recognition that massive nickel deposits can occur in extrusive rocks has important exploration implications.

SUMMARY

The growing recognition of the relationship of ore deposits to volcanic processes was evident at every step on this field trip. A synthesis of these ideas was given by Hutchinson, Ridler, and Suffel in a paper in CIM Bull. (April 1971, p. 48-57) which makes excellent reading. I found the trip very educational and well worth the expense.

F. T. Graybeal

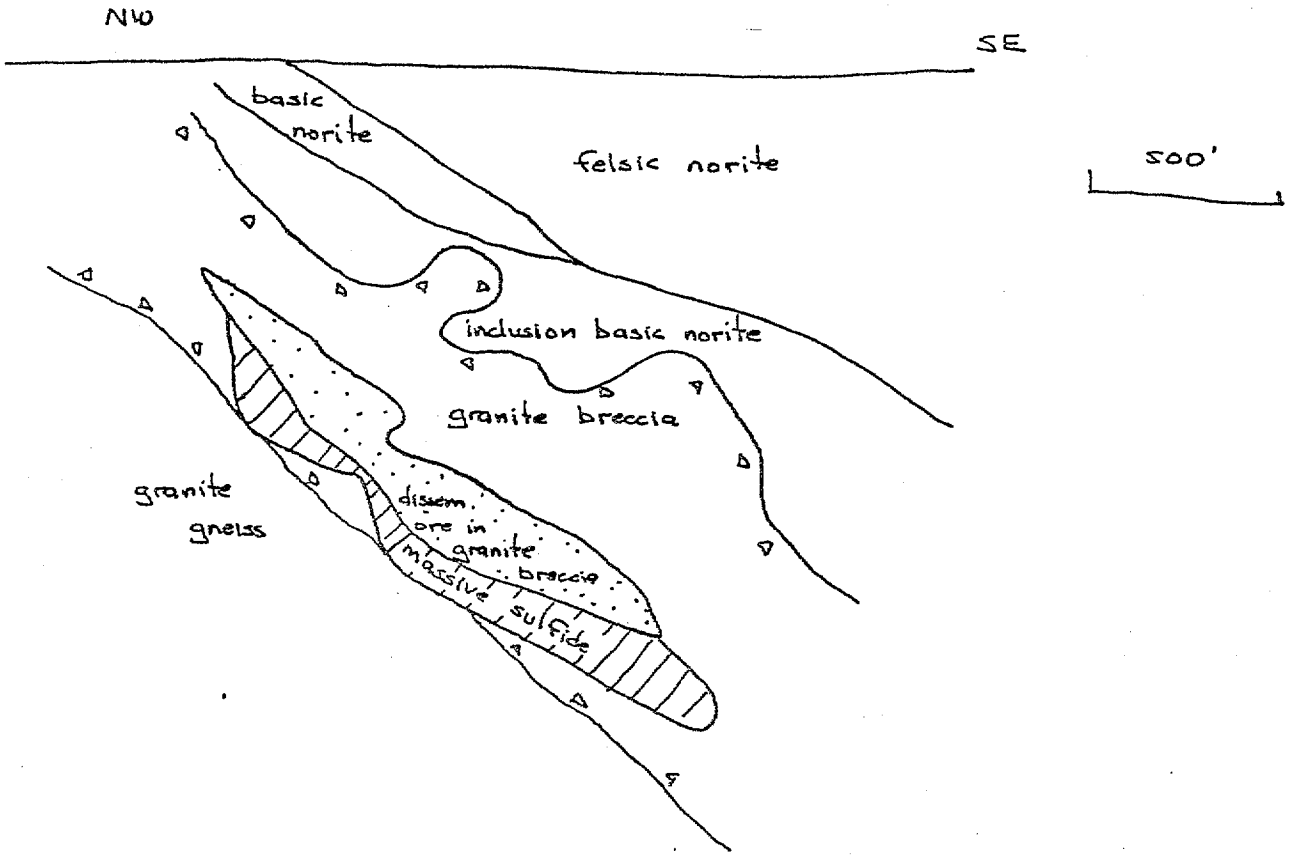
F. T. Graybeal

FTG:lb
Attachs.

COLEMAN MINE

This is a North Range deposit owned by INCO and appears to be part of the same deposit mined by Falconbridge's adjacent Strathcona mine. The grade is 2.5-3% combined Cu-Ni with a ratio of about 1:1. They mine 4000 tpd at costs of roughly $5-8/ton. The ore occurs in a granite breccia and an inclusion basic norite (which is a breccia with basic norite fragments). These two rocks form what is now being called the sublayer zone of the Sudbury irruptive. The sublayer zone lies below the norite and is apparently being increasingly recognized as an important host for ore in this district.

The disseminated granite breccia and massive sulfide zone have a pyrrhotite:pentlandite ratio of 20:1 and is usually ore. The inclusion basic norite has ratios usually about 50:1 and thus is never ore.



APPENDIX 2

VAUZE MINE

From a talk given by Colin Spence
at Noranda, Quebec; May 17, 1973

GENERAL GEOLOGY

Within the Noranda district the Mine series of rhyolites contain most of the major mines. It is the third of five, mappable andesite-rhyolite series. Rhyolites of the third series tend to be spherulitic, aphanitic, and strongly fluidal. All orebodies in the third series have alteration pipes. The fourth series of rhyolites contain 2 known orebodies and are porphyritic and magnetic. The first, second, and fifth series of rhyolites are essentially barren.

Within the Mine series the Amulet rhyolite is an important host rock for ore as at least three mines lie at its top. It is overlain by the Waite andesite as shown on Figure 1. Overlying the Waite andesite at the north end of the district is the Waite rhyolite which has numerous mines at its top. The Waite and Amulet rhyolites are all overlain by the Amulet andesite.

Figure 1 shows that the orebodies lie at the top of two different rhyolites, but are overlain by a single andesite. Therefore, the orebodies are not thought to have formed until the second rhyolite was deposited.

The rhyolites are actually siliceous dacites (due to a lack of K-spar) and are thought to have flowed considerable distances. Individual flows 300 ft. thick can be traced for 6 miles.

THE OREBODY

The Vauze mine contained 200,000 tons at 6% Cu, 6% Zn, 2 oz. Ag, and 0.03 oz. Au. It also contained 200,000 tons of 3% Cu ore in an alteration pipe. It cost $1 million to get the mine into production and in the first 13 months of operation it returned $3 million profit.

The massive sulfide lens is associated with a thickening of the underlying rhyolite as shown on Fig. 2. The history of ore deposition is thought to have started with construction of the rhyolite dome followed by rhyolitic phreatic explosion breccia, sulfide sinter deposit of pyrrhotite-chalcopyrite, development of chalcopyrite-bearing talus breccia, deposition of pyrite-sphalerite, and ending with an andesite flow. At the time of discovery the orebody lay 14 ft. below the surface underneath completely fresh andesite.

The phreatic explosion breccia consists of fragments of material from the upper part of the dome, suggesting it was a near-surface event related to the hot spring activity and not a deep-originating vent cleaning eruption. The talus breccia contains fragments of the massive pyrrhotite-chalcopyrite ore and chlorite alteration pipe, but is conformably overlain by the massive pyrite-sphalerite ore.

The alteration pipe contains no pyrrhotite or sphalerite. The intensity of the chlorite alteration increases inward. Sericite alteration of the rhyolite is abundant around the edge of the chlorite. The pipe increases in size downward, but becomes more diffuse. Chlorite in the center of the pipe is Fe-rich and in the periphery is Mg-rich. Several samples of intense chlorite with orthoclase pods up to 1 inch in diameter were collected from the dump.

A chert bed from 6 inches-2 ft. thick overlies the sulfides and is widespread in this area at the top of the Waite rhyolite. Spence suggested that the chert may result from intense chloritization of the rhyolite which reduces the SiO_2 content from 75% to 30%.

The paleogeography of this area at the time of ore deposition is likened by Spence to the current appearance of the Taupo hot spring in New Zealand.

Figure 1. Paleogeography at ore deposition

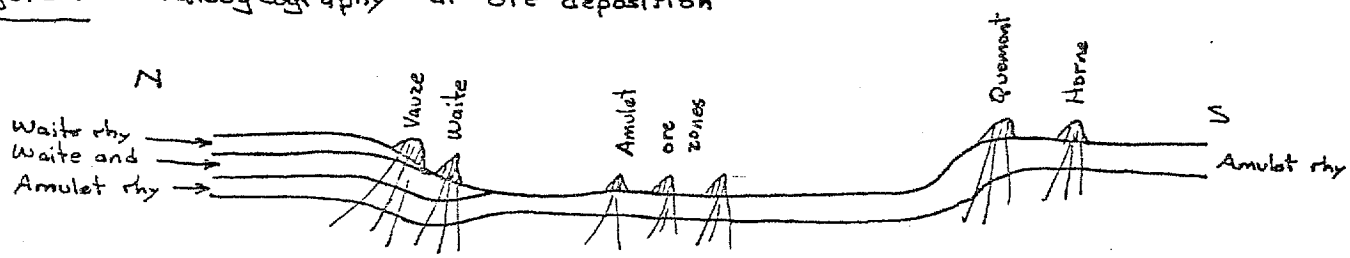
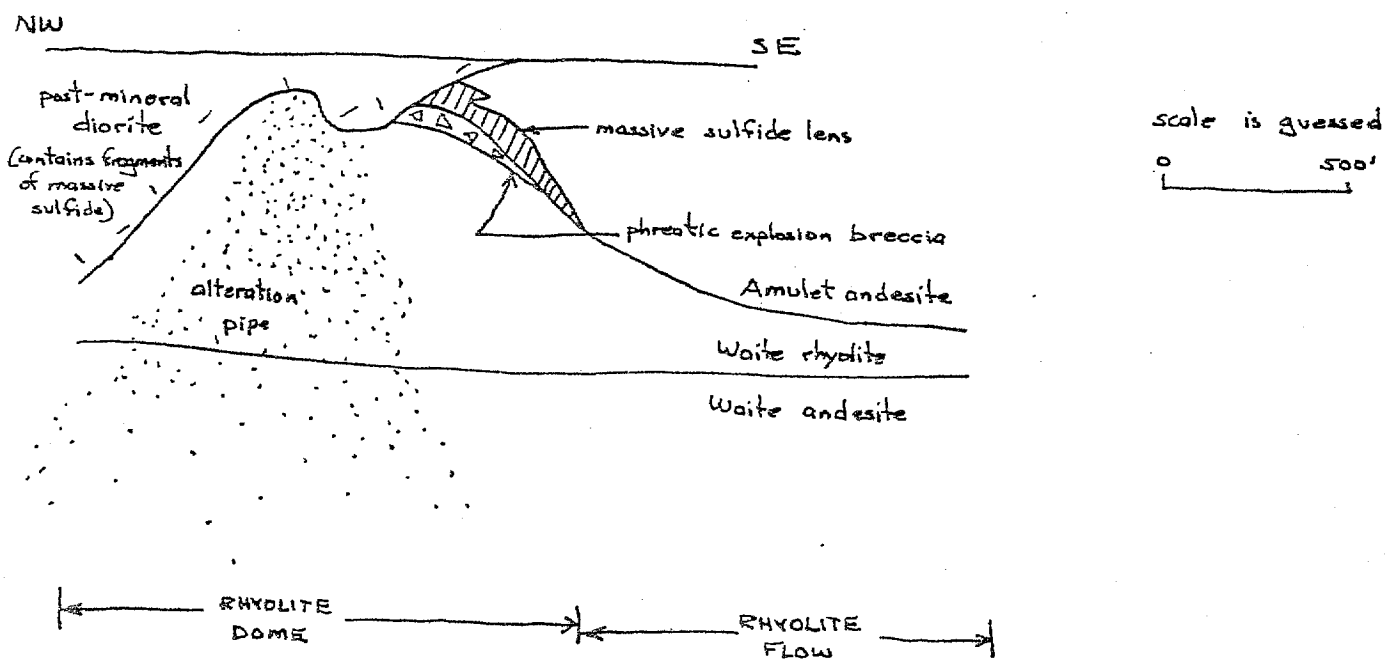


Figure 2. Cross-section of the Vauze mine



3-30-73

FROM: J. H. COURTRIGHT

TO: Del Harper

Will plan to attend GSA meeting Thursday morning in Knoxville and return Tucson in the afternoon.

Expect to arrive in Knoxville Friday nite, April 6, as we have a session on Buchans scheduled for Saturday afternoon.

Saludos

J.H.C.

cc: JT Collins

RECEIVED
MAR 22 1973
EXPLORATION DEPT.

New York, March 20, 1973

J. H. C.

MAR 20 1973

MEMORANDUM FOR: Division Supervisors
Asarco Exploration Department
North America

Tennessee Mines

Please bring your own hard hats, picks, lamp belts (but not lamps), etc. to Knoxville. Plenty of lamps are available while the mines are on strike. The mines are relatively dry so rubber boots are not necessary.

Please inform Del Harper if you want to attend the Thursday morning GSA program.

John J. Collins

cc:JHCourtright
RJLacy
MPBarnes
WLKurtz
RKKirkpatrick
KWhiting
SAAnzalone
RLBrown
DDHarper

AMERICAN SMELTING AND REFINING COMPANY
EXPLORATION DEPARTMENT
P. O. BOX 5747, TUCSON, ARIZONA 85703

J. H. COURTRIGHT
CHIEF GEOLOGIST

1150 NORTH 7TH AVENUE
TELEPHONE 602-792-3010

March 19, 1973

Dr. Fredrick C. Kruger, Chairman
Department of Applied Earth Sciences
Stanford University
Stanford, California 94305

Dear Dr. Kruger:

Regarding ASARCO student grants, Mr. J.J. Collins has asked me to point out that coincident with the discontinuance of the $1,000.00 Stanford scholarship, the fellowship grant was increased by the same amount, and that an equal grant ($2,000.00) is available to the school for equipment or other needs.

I have your letter of March 14th, and will be looking forward to tours of Silver Bell and Mission with your group, March 28th and 29th.

Very truly yours,

J.H. Courtright

J.H. Courtright

JHC:kre

cc: J.J. Collins

From: J. J. Collins

To:

D. D. Harper - Please attend or send a deputy

W. G. Hoskins - Please attend

J. H. Courtright

RECEIVED
FEB 26 1973
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JJC read
FEB 22 1973

9th ANNUAL FORUM ON THE GEOLOGY OF INDUSTRIAL MINERALS

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Illinois State Geological Survey
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J. H. C.
MAR 5 - 1973

April 26-28, 1973

Paducah, Kentucky

PROGRAM OF EVENTS

Thursday, April 26, 1973

3:00 - 5:00 p.m.)
7:00 - 9:00 p.m.) REGISTRATION and INFORMATION: lobby of Ramada Inn.

7:30 - 8:30 p.m. BUSINESS MEETING, Banquet Room, Ramada Inn.
Robert L. Major, Illinois State Geological Survey, presiding

8:30 - 10:00 p.m. RECEPTION, Banquet Room, Ramada Inn, Cash beer bar.

Friday, April 27, 1973

8:00 - 9:00 a.m. REGISTRATION and INFORMATION: lobby of Cabana Club Convention Center

9:00 - 9:10 a.m. OPENING CEREMONIES, Cabana Club Convention Center, Main Hall
Preston McGrain, Assistant State Geologist, Kentucky Geological Survey, Lexington, Kentucky, presiding.

WELCOMING REMARKS by the Honorable Dolly McNutt, Mayor of Paducah.

TECHNICAL SESSION I:

Gill Montgomery, Vice President and General Manager
Minerva Oil Company, Eldorado, Illinois, presiding

9:10 - 9:30 a.m. *"Fluorine Resources - An Overview"* (tentative title), Gill Montgomery, Vice President and General Manager, Minerva Oil Company, Fluorspar Division, Eldorado, Illinois.

9:30 - 10:00 a.m. *"The Environments of Deposition of Fluorspar,"* Robert M. Grogan, Manager, Geology Division, Purchasing Department, E. I. DuPont de Nemours & Co., Wilmington, Delaware.

10:00 - 10:30 a.m. *"The Geology of the Derbyshire Fluorspar Deposits, United Kingdom,"* Joseph E. Mason, Division Geologist, La Porte Industries, Sheffield, England.

10:30 - 11:00 a.m. COFFEE BREAK

11:00 - 11:30 a.m. *"Geology of Mexican Fluorite Deposits,"* Greenleaf W. Pickard, Assistant Chief Geologist, Asarco Mexicana, S.A. H. Del Parall, Chihuahua, Mexico.

11:30 a.m. - 12:00 p.m. *"Geology of Fluorspar Deposits of the Western United States,"* Ronald G. Worl, Geologist, U. S. Geological Survey, Denver, Colorado.

12:00 - 1:30 p.m. LUNCH, Cabana Club dining room.

TECHNICAL SESSION II:

James C. Bradbury, Head, Industrial Minerals Section
Illinois State Geological Survey, Urbana, Illinois, presiding

1:30 - 2:00 p.m. *"Fluorite-Barite Deposits in the Mississippi Valley in Relation to Major Structures and Zonation,"* Allen V. Heyl, Jr., Geologist, U. S. Geological Survey, Denver, Colorado.

2:00 - 2:30 p.m. *"Geology of the Illinois-Kentucky Fluorspar District,"* (tentative title) Robert D. Trace, Geologist, U. S. Geological Survey, Princeton, Kentucky.

2:30 - 3:00 p.m. *"The Structure of the Fault Systems in the Illinois - Kentucky Fluorspar District,"* John W. Hook, District Geologist, Reynolds Metals Company, Salem, Kentucky.

3:00 - 3:30 p.m. COFFEE BREAK

3:30 - 4:00 p.m. *"The Geology and History of Dyer's Hill Mine, Livingston County, Kentucky,"* John S. Tibbs, Geologist, Pennwalt Corp., Salem, Kentucky.

4:00 - 4:30 p.m. *"The Eagle-Babb-Barnes Fluorspar Project, Crittenden County, Kentucky"* F. Boyce Moodie III, Exploration Consultant, Cerro-FFL Group, Salem, Kentucky and Preston McGrain, Kentucky Geological Survey.

6:00 - 7:00 p.m. SOCIAL HOUR, Cabana Club Convention Center - Cash bar.

7:00 - 9:00 p.m. BANQUET, Cabana Club Convention Center, Preston McGrain, Kentucky Geological Survey, presiding.

After Dinner Speech: (topic to be announced later) Ray McCormick, Texas Gas Transmission Corporation, Owensboro, Kentucky.

Saturday, April 28, 1973

FIELD TRIPS

7:45 a.m. Meet buses at Ramada Inn.

8:00 a.m. - 6:00 p.m. Full day field trip to Illinois Fluorspar District to observe bedded and vein ore occurrences underground at mines of Ozark-Mahoning Company and Minerva Oil Company (Fluorspar Division) plus tours of surface preparation plants (as time permits). Registration limited to 85 persons on a first come, first serve basis. Cost, including box lunch, guide book, road log, and bus, will be $10.

8:30 a.m. - 4:00 p.m. Alternate field trip for those not accommodated on first trip. This trip will observe some surface features in the Western Kentucky Fluorspar Mining District, including areas of Dyer's Hill Mine (now inactive) and the Cerro-FFL project (under development). Travel will be by private cars. Registration will be limited to 15 cars (60 persons). Cost including box lunch and road log will be approximately $5.

LOCATION AND ACCESS: Paducah (population 31,627) is the largest city in western Kentucky lake region. It is the county seat of McCracken County and located at the junction of Tennessee and Ohio Rivers. Kentucky and Barkley Lakes are situated some 20-25 miles to the east. The city is served by U. S. Highways 45, 60, 62, and 68, by Greyhound and Brooks Bus lines, and by Delta and Ozark Airlines. Airline service is via Barkley Field, which is located about 8 miles west of the city on U. S. 60. Limousine service is available from the airport to major motels. Rental car service is also available at airport. For further information, contact: Tourist Information Bureau, 2701 Park Avenue, Paducah, Kentucky 42001.

REGISTRATION: Pre-registration for Forum will be required. All registrations must be received by April 10, 1973 at the latest. Registration fee includes:

a. admission to technical sessions
b. lunch, Friday, noon
c. coffee breaks
d. banquet, Friday evening
e. copy of proceedings
f. list of names and addresses of all attendees

Tickets for field trips and banquet tickets for wives and other guests will be extra.

Use enclosed registration form to register. Please do not register more than one person on a form. Please xerox extra forms if registering more than one person. Payment must be enclosed to hold registration reservation.

ACCOMMODATIONS: The Ramada Inn (1380 South Beltline Highway, Paducah, Kentucky 42001) will be the official headquarters of the Forum. The Ramada has promised to hold 80 rooms for Forum attendees. If you wish to stay at the Ramada Inn, please use the enclosed reservation card. It is suggested that this be done early as it is expected that attendance will exceed capacity of Ramada. For additional accommodations, see enclosed map and rate sheet.

FIELD TRIPS:

1. Illinois Fluorspar Mining District Trip.

   Participation on this trip will be by advanced pre-registration and will be limited to 85 persons plus tour leaders. Hard hats and lights are required and rubber footwear and field clothes are recommended. All equipment must be supplied by individuals. Transportation will be by bus. There is no provision for taking private cars and no provision for early departure. Participants should not count on being back in Paducah before 6:30 p.m.

2. Western Kentucky Fluorspar Mining District.

   This trip is offered as alternate (supplementary) trip for those unable to be accepted on the Illinois trip. Participation will again be only by advanced, pre-registration and will be limited to 60 persons. Travel will be by private cars (15 maximum). Hard hats are required; heavy shoes and field clothes are recommended. Particpiants must supply their own equipment.

Registration for the field trips will be on a first come, first serve basis. You will be notified later of your acceptance and billed for the trip at that time. Those who wish to attend only a field trip and not the symposium will be permitted to do so only if there are openings after others attending the symposium are registered.

REGISTRATION FORM*

9th FORUM ON THE GEOLOGY OF INDUSTRIAL MINERALS

April 26-28, 1973
Paducah, Kentucky

(Please print clearly or type)

NAME: _____

TITLE: _____

COMPANY OR ORGANIZATION: _____

_____

BUSINESS ADDRESS: _____
(include ZIP code) _____

_____

BUSINESS PHONE (include area code): _____

*Please do not register more than one person on this sheet. Write for extra forms or xerox copy of this form for additional registrants.

Check where appropriate:

/___/ Registration for Forum..... $20.00
(includes lunch, banquet, and copy of proceedings)

/___/ Extra banquet tickets @ $7.50 for guests..... _____

Total Enclosed $_____

Please register me for the Illinois Fluorspar Mining District Trip April 28, 1973. /___/

If the Illinois field trip is filled, are you interested in taking the alternate trip through the Western Kentucky Fluorspar District? Yes /___/ No /___/

If yes, do you expect to have a car and would you be willing to drive? Yes /___/ No /___/

If yes, how many persons could you take with you? _____

My wife is planning to come with me. /___/

Please return form to: Robert L. Major
Illinois State Geological Survey
200 Natural Resources Building
Urbana, Illinois 61801

Make checks payable to "Industrial Minerals Forum."

MAJOR PADUCAH MOTELS

HOLIDAY INN: 727 Joe Clifton Drive, Ph. 443-7521; 140 units, air cond. colored TV, swimming pool, dining room, cocktail lounge, airport limousine service*. Single $12, Double $15.50, 2 Double beds $17.50.

RAMADA INN: 1300 S. Beltline, Ph. 443-8751: 101 units, dining room, colored TV, air cond, cocktail lounge, swimming pool, coffee shop - restaurant, airport limousine service*. Single $12 - Commercial $11 - Double $15-$16.

TRAVELODGE MOTEL: 1234 Broadway to Ky. Ave., Ph. 443-8401; 58 units, air cond. TV-(some bl & wh, some colored) heated swimming pool, private balconies. Long boy beds, airport limousine service*. Restaurant & Cocktail lounge across street. Single $11 - Double $13 - 2 Double Beds $16 - $3 ea. extra person.

CONTINENTAL INN: Bridge & Beltline, U. S. 60-62-68 E. (& S.) Ph. 443-6504; 103 units, air cond., cocktail lounge, restaurant, swimming pool, colored TV, airport limousine service*. Single $11 - Double $14 - 2 Double beds $16-$22.

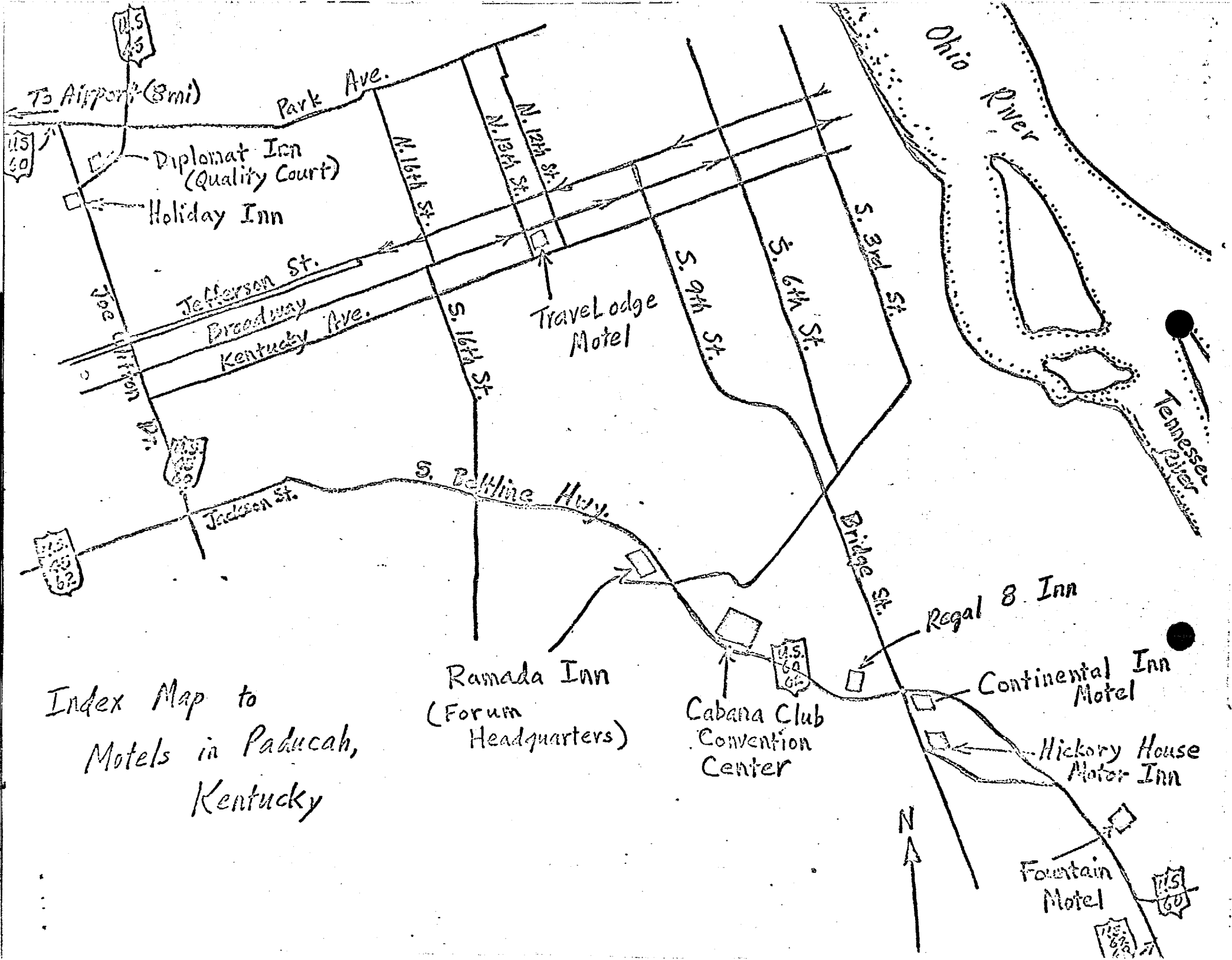
DIPLOMAT INN: 2701 Thompson Ave., U. S. 45 N. Ph. 443-6573; 61 rooms, dining room, cocktail lounge, swimming pool, air cond., colored TV. Single $11 - Double (2 beds) $16 - each addl. person $3. Airport limousine service*.

FOUNTAIN MOTEL: U. S. 60-62 E. - 68 S., Ph. 442-3595; 36 units, air cond., TV - swimming pool, restaurant adjacent. Single $7 - Double $9-$10.

HICKORY HOUSE MOTOR INN: 2504 Bridge St., Ph. 442-1601; 36 units, swimming pool, radio & TV (some bl & wh - some colored) Single $7-$8; Double $10-$11; restaurant.

REGAL 8: 2150 S. Beltline Hwy. Ph. 442-6171; 79 units, swimming pool, cocktail lounge; restaurant adjacent; air cond., color TV, airport limousine service*. Single $8 - Double $10 (1 bed), $12 (2 beds).

* Passengers will be delivered to and picked up from these motels, if the service is notified.



Index Map to Motels in Paducah, Kentucky

The University of Western Ontario, London 72, Canada

Faculty of Science
Department of Geology

J. H. C.

JAN 31 1973

January 24, 1973.

RECEIVED
JAN 31 1973
EXPLORATION DEPT.

Mr. J. H. Courtright,
Chief Geologist,
American Smelting and Refining Co.,
Exploration Department,
P. O. Box 5747,
Tucson, Arizona 85703.

Dear Mr. Courtright:

Thanks very much for your letter of January 17th and the complimentary words on our students' guidebook. Enclosed is a spare copy of that guidebook. Unfortunately this one has a slightly smudged cover but it is the only spare left at this time. Thanks also for offering to come out with us again. We certainly would appreciate it and it's something for us all to look forward to. I really do believe these field trips are a worthwhile activity for a geology department and the thing that makes them go well is having people like yourself participate.

Very best regards,

Yours truly,

R. W. Hodder,
Assistant Professor.

RWH:SW

RECEIVED
OCT 5 1970
EXPLORATION DEPT.

J. H. C.
DEC 16 1970

Registration List
SEG Northwest Field Conference
Sept. 7-10, 1970

Ahlstrand, Dennis, Geologist, Vanguard Exploration Co., Metaline Falls, Washington

Anderson, Eskil, Geologist, Consultant, Spokane, Washington

Armstrong, Frank C., Geologist, U. S. Geological Survey, Spokane, Washington

Arnold, C. F., Regional Geologist, Phelps Dodge Corporation, Salt Lake City, Utah

Balla, John, Holt, Inc., Spokane, Wash.

Beavan, Roy, Canadian Superior Exploration Ltd., Vancouver, B. C.

Binon, Layton C., Geologist, Burlington Northern Inc., St. Paul, Minnesota

Booth, G. G., Cominco American, Spokane, Wash.

~~Bourret, Weston, Vice President, Utah Construction & Mining Co., San Francisco, Calif.~~

Bower, Richard R., Senior Minerals Geologist, Humble Oil & Refining Co., Marquette, Mich

Bradbury, James C., Geologist, Illinois State Geological Survey, Urbana, Illinois

Bradley, O. E., Senior Geologist, Canadian Exploration Limited, Vancouver, B. C.

Bradshaw, Herb, Geologist, Hillside Mines, Inc., Spokane, Washington

Broderick, John, National Lead, Spokane, Washington

Brown, John S., Retired, Townson, Maryland

Brumbaugh, D., Geologist, Bear Creek Mining Co., Spokane, Wash.

Bryner, Leonid, Chief Geologist, American Exploration & Mining Co., San Francisco, Cal.

Campbell, Neil, Consultant, Spokane, Washington

Chadwick, Russell, Geologist Consultant, Spokane, Washington

Cloke, Paul L., Professor, University of Michigan, Ann Arbor, Michigan

Collins, John J., Asst. Vice Pres., American Smelting & Refining Co., New York, N.Y.

Cook, J. D., District Geologist, Norandex, Inc., Spokane, Washington

Courtright, Harold, Chief Geologist, American Smelting & Refining Co., Tucson, Ariz.

Cunningham-Dunlop, P. K., Geologist, E. I. Du Pont de Nemour's & Co., Wilmington, Del.

Czamanske, Gerald K, Geologist, U. S. Geological Survey, Menlo Park, California

Dohms, Peter A., The New Jersey Zinc Co., Tucson, Arizona

Ehinger, Robert F., Cominco American, Lexington, Kentucky

Frankovich, Frank J., Consulting Geologist, American Silver & Atlas Mining Companies
Spokane, Washington

Freedman, Jacob, Professor, Franklin & Marshall College, Lancaster, Pennsylvania

Fulton, Robert B., E. I. du Pont de Nemour's & Co., Wilmington, Del.

Fyles, James T., Geologist, British Columbia Dept. of Mines & Petroleum Resources, Victoria, British Columbia

Garwood, R. G., Regional Manager, American Exploration & Mining Co., Spokane, Wash.

Gerdemann, Paul E., Chief Geologist, St. Joseph Lead Company, Bonne Terre, Missouri

Goddard, C. C., Geologist, Consultant, Fullerton, California

Greene, Adrian V., Geologist, ASARCO, Bunker, Missouri

Griggs, Allan B., Geologist, U. S. Geological Survey, Menlo Park, California

Haas, John L., Jr., Geologist, U. S. Geological Survey, Washington, D. C.

Hagni, Richard D., Professor, University of Missouri, Rolla, Missouri

Hare, Edward H., Cominco American, St. Charles, Missouri

Harper, Delbert D., Geologist, ASARCO, Knoxville, Tennessee

Heidrick, Tom L., Asst. Professor, Washington State University, Pullman, Washington

~~Hollister, Victor,~~ Exploration Manager, ~~Duval Corporation,~~ Tucson, Arizona

Hull, Donald A., Geologist, Homestake Mining Company, Spokane, Washington

Huntting, Marshall T., Supervisor, Div. Mines & Geology, Olympia, Washington

Jackson, Stewart A., Cominco American, Cookville, Tennessee

Johns, Willis M., Geologist, Montana Bur. Mines & Geology, Butte, Montana

~~Johnson, Henry S., Jr., Consulting Geologist, Sandhill Resources, Inc., Columbia, S.C.~~

Johnson, Robert F., Geologist Consultant, Berkeley, California

Juhas, Allan P., Texas Gulf Sulphur Co., Denver, Colorado

Kesten, Norman S., Chief Geologist, Northwestern Mining Dept. ASARCO, Wallace, Idaho

Kidwell, Albert L., Research Associates, ESSO Production Research Co., Houston, Texas

Kinkel, A. R., District Geologist, Callahan Mining Corporation, Osburn, Idaho

Koehler, G. F., Chief Geologist, Cominco American Inc., Spokane, Washington

Kuchenmeister, Joseph, The Bunker Hill Co., Kellogg, Idaho

Lasmanis, Raymond, Geologist, Superior Oil Co., Spokane, Washington

Lindgren, Donald W., President, Lindgren Exploration Co., Wayzata, Minnesota

Macdonald, Alan, Geology student, University of British Columbia, Vancouver, B. C.

McConnel, Roger, Geologist, The Bunker Hill Co., Kellogg, Idaho

McGillis, John L., District Geologist, Duval Corporation, Salt Lake City, Utah

Melrose, T. G., Geologist, Bethlehem Steel Corporation, Lakewood, Colorado

Myers, Harold E., Mine Geology Supervisor, St. Joseph Lead Co., Bonne Terre, Missouri

Nash, J. Thomas, Geologist, U. S. Geological Survey, Menlo Park, California

Nold, John L., Cominco American, Spokane, Washington

Oscarson, P. E., Mining Engineer Consultant, Spokane, Washington

Park, Charles F., Jr., Retired, Magdalena, New Mexico

Pettigrew, Kenneth, The Bunker Hill Co., Kellogg, Idaho

Pilkington, H. D., Geologist, International Minerals & Chem. Corp., Vancouver, B. C.

Pullen, Thomas H., District Geologist, Union Pacific Corporation, Spokane, Washington

Reed, William M., Mining Geologist, Clinton, Washington

Reinbold, Grover, Supv. Geologist, Humble Oil & Refining Co., Cookeville, Tennessee

Renfro, A. R., Senior Geologist, Teton Exploration Drilling Co., Inc., Casper, Wyoming

Rhoades, David A., Geologist, National Lead Company, New York, N. Y.

Ridge, John D., Professor of Geology, The Pennsylvania State Univ., University Park, Penn.

Robinson, Raymond F., Regional Manager, Halt-McPhar, Inc., Reno, Nevada

Sangster, D. F., Research Scientist, Geological Survey of Canada, Ottawa, Ontario

Shannon, Spencer S., Jr., Assoc. Professor, University of Texas, El Paso, Texas

Sherry, Richard, Bear Creek Mining Co., Spokane, Wash.

Shockey, P. N., Chief Geologist, Teton Exploration Drilling Co., Inc., Casper, Wyoming

Slawson, William F., Professor, University of British Columbia, Vancouver, B. C.

Smith, Charles S., Geologist, Cities Service Minerals Corporation, Jonesboro, Arkansas

Smith, Jess, Geologist, Superior Oil Company, Spokane, Washington

Springfield, Joseph, Cominco American, Spokane, Wash.

Springer, Donald C., Geologist, Osburn, Idaho

Sproule, R. W., Cominco, B. C.

Staatz, Mortimer H., Geologist, U. S. Geological Survey, Denver, Colorado

Stickney, Webster F., Geologist, Occidental Minerals Corporation, Carthage, Tennessee

Swinderman, J. N., Geologist, Cities Service Minerals Corporation, Spokane, Washington

Tanner, Tyryll, The Bunker Hill Co., Kellogg, Idaho

Turner, I. L., Geologist, Vanguard Exploration Company, Spokane, Washington

Trautwein, Breck J., Geologist, National Lead Company, New York, New York

Tweto, Ogden, Geologist, U. S. Geological Survey, Denver, Colorado

Walker, W. J., Senior Geologist, Phelps Dodge Corporation, Douglas, Arizona

Watson, K. D., Professor of Geology, University of California, Los Angeles, California

Webb, J. H., Geologist, Teton Exploration Drilling Co., Inc., Casper, Wyoming

Wedow, Helmuth, Jr., Geologist, U. S. Geological Survey, Knoxville, Tennessee

Weis, Paul L., Geologist, U. S. Geological Survey, Spokane, Washington

Weissenborn, Albert E., Research Geologist, U. S. Geological Survey, Spokane, Washington

Wells, John D., Geologist, U. S. Geological Survey, Denver, Colorado

Westphal, W. H., Vice-President, Intercontinental Oil Corporation, Denver, Colorado

Whiting, Keith, Supervisor, NW U. S. Explor. Div., American Smelting & Refining Co., Spokane, Washington

Wilson, Ken, Consulting Geologist, San Francisco, California

Worthington, Joseph E., Regional Manager, Cyprus Mines Corporation, Spokane, Washington

Yates, Robert G., Geologist, U. S. Geological Survey, Menlo Park, California

AMERICAN SMELTING AND REFINING COMPANY
SOUTHWESTERN EXPLORATION DEPARTMENT
P.O. BOX 5795, TUCSON, ARIZONA 85703

J. H. COURTRIGHT
CHIEF GEOLOGIST
L. P. ENTWISTLE
ASSISTANT CHIEF GEOLOGIST
W. E. SAEGART
ASSISTANT CHIEF GEOLOGIST

1150 NORTH 7TH AVENUE
TELEPHONE 602-792-3010

J. H. C.
MAY 22 1969

May 21, 1969

Mr. Jerry C. Ryan, Controller
Bagdad Copper Corporation
Bagdad, Arizona 86321

Dear Mr. Ryan:

On behalf of the ASARCO Engineers who attended the sub-section open pit meeting at Bagdad last Friday, I would like to thank you and your staff for a most informative and enjoyable visit. Those of us in the Exploration Department were especially pleased with the separate tour of the pit and surrounding areas, which was very well conducted by Mr. Rana Medhi.

As I indicated during our dinner conversation, I am interested in recent exploration developments of the Bagdad Copper deposit. We hope to schedule an appointment with Mr. Lincoln to discuss the possibility of updating the 1956 Bagdad evaluation prepared by Kenyon Richard, J.H. Courtright and other engineers from our staff. Data used in preparing that study was made available largely due to the excellent relationship which has always existed between our companies. It is our sincere wish to continue to maintain close laison with your organization. I will look forward to an opportunity to continue our conversation and to meet other members of your staff.

Very truly yours,

W. E. Saegart

W.E. Saegart

WES:lzb

cc JJCollins
TASnedden
RFWelch
JHCourtright

Blind note on ASARCO copies:

The following statement is extracted from KER-JHC report of Dec. 29,1956. "However, it certainly is worth noting that Bagdad has one of the larger potentials of low grade copper "ore" in the United States."

From my conversation with the Bagdad Resident Geologist, I conclude that the limits of ±0.5% Cu have yet to be determined--to the northeast, to the west and at depth. The eventual development of several hundred million tons of low grade Cu-Mo ore is a reasonable expectation. By updating the 1956 report, I would hope to develop factual documentation of the above inferences.

W.E.S.

AMERICAN SMELTING AND REFINING COMPANY
Tucson Arizona

April 29, 1969

MEMORANDUM TO:

Bruce E. Kilpatrick
Stephen R. Davis
Ron D. Karvinen
Sergei E. Zelenkov
Paul D. Bauer

I have been advised by Mr. J.W. Murray, Mine Superintendent, Magma Copper Company, that their quota for the underground trip at Superior was filled prior to my letter of April 22.

Mr. Murray suggests that we check with him at some later date and that a tour can then probably be arranged.

J.H. Courtright

J.H. Courtright

JHC:lzb

cc: WESaegart

J. H. C.

APR 29 1969

Magma Copper Company

SUPERIOR DIVISION
SUPERIOR, ARIZONA

April 28, 1969

Mr. J. H. Courtright
American Smelting & Refining Company
Southwestern Exploration Department
P. O. Box 5795
Tucson, Arizona 85703

Dear Mr. Courtright:

We are in receipt of your letter of April 22, 1969 indicating your desire to attend the meeting of the Underground Division on May 2nd. We would be most happy to have you and your associates attend, however the tour quota has now been filled.

Please check with us at a later date, possibly after the middle of May and we would be pleased to take you and your associates on a tour of our underground property at that time.

Yours very truly,

J. W. Murray/m.

J. W. Murray
Mine Superintendent

mms

April 22, 1969

Mr. J.W. Murray, Chairman
Underground Division
Magma Copper Company
Superior Division
Superior, Arizona

Dear Mr. Murray:

I would like to arrange for the following members of our staff to attend the meeting of the Underground Division at Superior, Friday, May 2:

Bruce E. Kilpatrick
Stephen R. Davis
Ron D. Karvinen
Sergei E. Zelenkov
Paul D. Bauer

I note your request that reservations be in by April 19, however, the announcement of the meeting was delayed in reaching my desk. Please advise if your quota is already full.

Yours very truly,

J.H. Courtright

JHC:lzb

cc: WESaegart
BEKilpatrick
SRDavis
RDKarvinen
PDBauer
SEZelenkov

M A G M A C O P P E R C O M P A N Y

S u p e r i o r D i v i s i o n

S u p e r i o r, A r i z o n a

March 18, 1969

ANNOUNCEMENT OF SPRING MEETING

Dear Member:

The Annual Spring Meeting of the Underground Division, Arizona Section of AIME will be held at the Superior Division of Magma Copper Company, Friday May 2, 1969, at the Superior Mine, Superior, Arizona. It will be a one day meeting and stag as is customary.

The program is as follows:

8:00 A.M.	Arrive at Mine Dress for Underground	Registration
9:00 A.M.	Surface Tour of Automated Sand	Cement Plant
9:30 A.M.	Proceed Underground	Tour Underground
12:30 P.M.	Leave Underground	Change for Lunch
1:30 P.M.	Luncheon	St. Mary's Center Sunset Drive, Superior
3:00 P.M.	Technical Discussion Period	St. Mary's Center

Spring Meeting Adjourned

Those planning on making the underground tour are requested to bring suitable clothing. Changeroom facilities will be provided.

Automobile parking space will be available behind the General Office which is located on N. Magma Avenue.

Please return the enclosed postal card by April 19, 1969.

J.W. Murray, Chairman
Underground Division
Arizona Section, A.I.M.E.

JWM/mms

BEK

MAGMA COPPER COMPANY

Superior Division

Superior, Arizona

3/22/69 J.P.K.

March 18, 1969

APR - 1969
Yes
F.P.K.

ANNOUNCEMENT OF SPRING MEETING

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9:30 A.M.	Proceed Underground	Tour Underground
12:30 P.M.	Leave Underground	Change for Lunch
1:30 P.M.	Luncheon	St. Mary's Center Sunset Drive, Superior
3:00 P.M.	Technical Discussion Period	St. Mary's Center

Spring Meeting Adjourned

Those planning on making the underground tour are requested to bring suitable clothing. Changeroom facilities will be provided.

Automobile parking space will be available behind the General Office which is located on N. Magma Avenue.

Please return the enclosed postal card by April 19, 1969.

J. W. Murray

J. W. Murray, Chairman
Underground Division
Arizona Section, A.I.M.E.

JWM/mms

April 22, 1969

Mr. B.J. Bonnis, Chairman
Bagdad Copper Corporation
Bagdad, Arizona 86321

Dear Mr. Bonnis:

I would like to arrange for the following members of our staff to attend the Spring Meeting, Open Pit Section, at Bagdad on Friday, May 16, 1969:

Bruce E. Kilpatrick
Stephen R. Davis
Ron D. Karvinen
Sergei E. Zelenkov
Paul D. Bauer

Thanking you in advance, I remain

Very truly yours,

J.H. Courtright

JHC:lzb

cc: WESaegart
BEKilpatrick
SRDavis
RDKarvinen
SEZelenkov
PDBauer

R. J. Bonnis
Chairman
Open Pit Section
A.I.M.E.
Bagdad Copper Corporation
Bagdad, Arizona 86321

Dear Member:

The Bagdad Copper Corporation will host the Spring Meeting A.I.M.E. Open Pit Section to be held in Bagdad on Friday, May 16, 1969.

In view of our remote location and lack of facilities, it would help us greatly to know well in advance the number of people who expect to attend. Your cooperation in completing the enclosed card and its return before April 25, 1969 would be greatly appreciated.

The program will begin at 9:30 A.M. and will consist of three papers by Bagdad personnel on various aspects and methods used at our operation. This will be followed by lunch and a tour of the mine and related plants. The session will conclude with a cocktail hour and dinner.

Bagdad has a 3600' paved runway for private planes. Advance arrangements can be made for pickup and delivery from the airport by calling or writing R. J. Bonnis or M. E. Gillo at Bagdad Copper Corporation (602) 633-2241.

Motel facilities in Bagdad are very limited, ten units are available by reservation, call (602) 633-2361. Accomodation arrangements will be left to the individual as ample facilities are available in Prescott and Wickenburg. Both towns are about 65 miles from Bagdad.

A map is attached for clarification of location.

Sincerely,

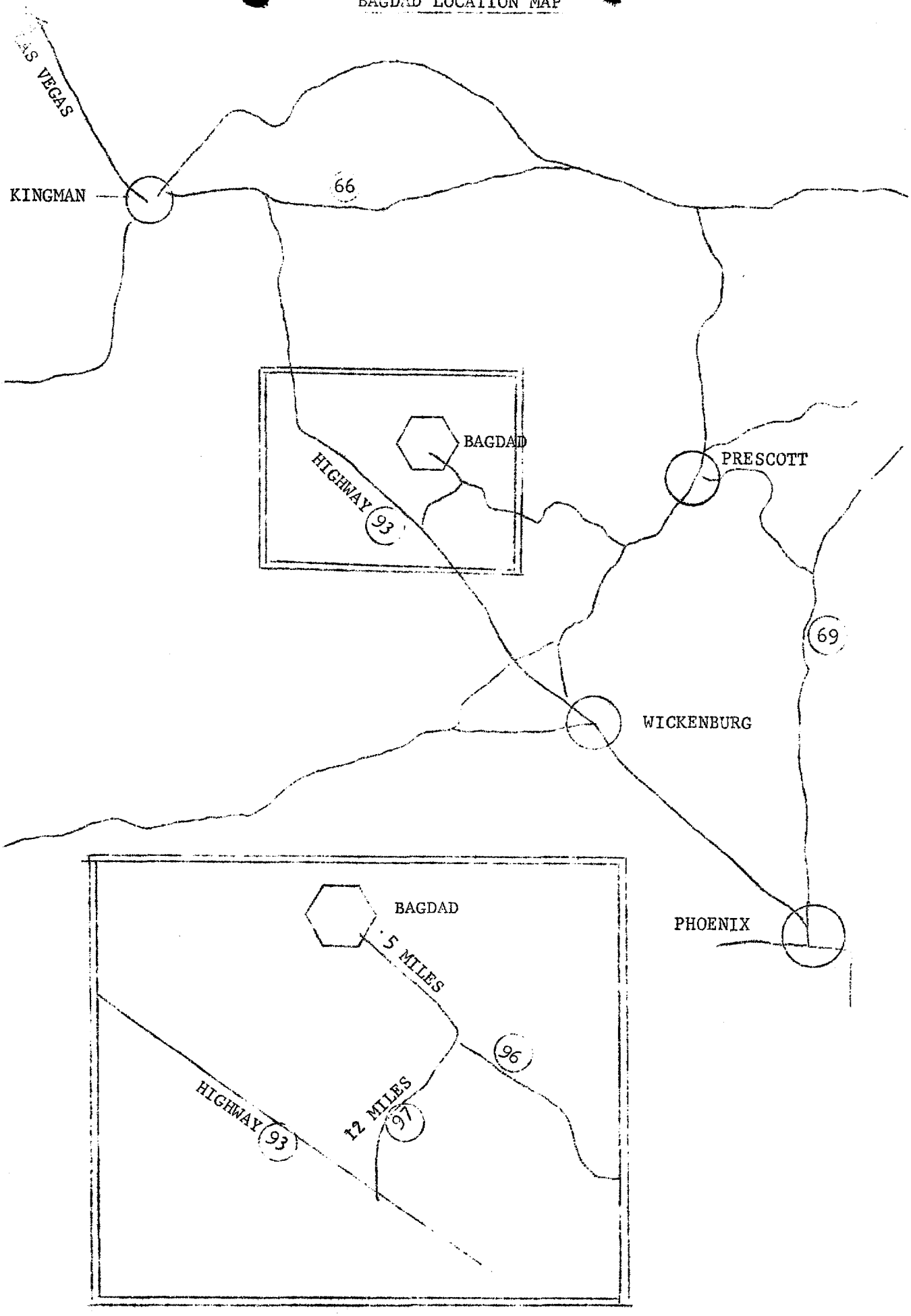
BAGDAD COPPER CORPORATION

R. J. Bonnis

R. J. Bonnis
Chairman

jcq/RJB
Enclosures

BAGDAD LOCATION MAP



2nd trip taken 4-26-69

AMERICAN SMELTING AND REFINING COMPANY
SILVER BELL UNIT
Silver Bell, Arizona

ARIZONA GEOLOGICAL SOCIETY FIELD TRIP - SILVER BELL, ARIZONA

Fluidized Intrusive and Extrusive Volcanics North of Oxide Pit.

Tour conducted by:

J. H. Courtright and J. A. Briscoe
American Smelting and Refining Company

INTRODUCTION

The complex geology of the area north of Oxide Pit was worked out by Mr. Barry N. Watson in conjunction with his Doctoral dissertation "STRUCTURE AND PETROLOGY OF THE EASTERN PORTION OF THE SILVER BELL MOUNTAINS, PIMA COUNTY, ARIZONA". All quotations and references in the following trip log refer to the above work, which can be obtained at either the Department of Geology, or the main library on the University of Arizona campus. Unfortunately Mr. Watson cannot conduct the trip because of his present assignment in Peru with the American Smelting and Refining Company.

Stop 1.

Traveling up stream and to the north we cross the contact of the dacite porphyry and the Paleozoic limestone.

"The most distinctive feature of the dacite porphyry is the presence of numerous small, rounded to subrounded quartz "eyes", (.04 to .15 inch in diameter) which, along with small white feldspar phenocrysts and a few biotite flakes, are set in an aphanetic matrix", (p. 27). The color varies from black to very light gray or white with all intermediate shades being found.

Note the numerous xenoliths in the dacite. These are also distinctive, and consist of pieces of quartzite, bedded or banded shaley material, silty material, and Pinal-like schist. The dacite contains a high percentage of xenoliths in the base and top of the unit with the central part containing few fragments, that are in places, identifiable only under the microscope. The percent of phenocrysts decreases upward in the section with the rock being about 65 to 75% phenocrysts at the base and only 50% phenocrysts near the top.

Watson has shown the dacite to be an intrusive, sill-like in form, and believes "that the nature of the rock reflects an implacement by fluidization" (P. 140) as explained below.

"The gas-and fragment-charged dacite porphyry magma (actually quartz latite in composition, suggesting greater viscosity and more explosive potential) rose along the Silver Bell fault zone into Paleozoic sediments. The higher the porphyry magma ascended, the more the confining pressure decreased, causing exsolution of gasses and thus lending an explosive and dilative nature to the intrusive material, ... Damp Amole-type Cretaceous (?) sediments were reached and more gas evolved. The porphyry material, expanding constantly, spread laterally to the northeast in the weak Cretaceous (?) sediments. Dialation occurred, as did the incorporation of fragments broken by the churning gas action.

The dacite porphyry probably surfaced in one or more places, venting forth gasses as it did..... The heat and vapor action caused an induration of the immediately overlying quartzofeldspathic clastic sediments (Claflin Ranch fm.), making them somewhat similar in appearance to the porphyry just intruded".

The dacite porphyry sill in this area is about 1,940 feet thick.

Stop 2.

Folding in the jointed dacite porphyry.

Stop 3.

Pebble dike cutting the dacite porphyry. The fragments appear to be mainly dacite porphyry.

Stop 4.

We have been walking through dacite porphyry in which numerous xenoliths can be seen. Boulders of Mt. Lord ignimbrite showing good eutaxitic texture cover the bottom of the wash.

On the west side of the wash the contact between the dacite and a syenodiorite porphyry dike may be seen. Note the chilled border of the syenodiorite giving way to porphyritic texture to the north. A narrow porphyritic syenodiorite dike crops out on the hill side several yards to the northeast (see map). The porphyritic syenodiorite and the syenodiorite porphyry dikes are considered by Watson, to be early phases of the later monzonite porphyry stocks and dikes, (P. 89,90). They are usually dark in color with smaller phenocrysts and contain pyoxenes in contrast to the monzonite which is lighter in color, has larger phenocrysts and contains amphibloes rather than pyroxenes.

Stop 5.

The hill on which we are now standing is a post-mineral Tertiary quartz latite dike. The general trend of these dikes is north and northwest, in contrast to the northeast and east-west syenodiorite and monzonite porphyry dikes.

To the northwest across the wash is a continuation of the quartz latite dike that is apparently off-set by faulting. This, however, is not the case. Watson suggests that the "discontinuous line of outcrop" ... "is caused not by faulting ... but by intrusion into a very broken and faulted terrane". These dikes can be up to 200 feet in thickness.

Stop 6.

As we leave the quartz latite porphyry dike we will turn to the east and more-or-less parallel one of the numerous east-northeast trending monzonite porphyry dikes which crops out on the hillside to the north of our route.

Stop 7.

From Stop 6 we have crossed dacite porphyry cut by a north-northwest trending quartz latite dike, (see map) most outcrops being covered with talus.

In the bottom of the stream, outcrops of Cretaceous Claflin Ranch sediments, metamorphosed by the intrusion of the dacite porphyry, may be seen. The contact zone between the dacite porphyry and the sediments is covered, but, note the destruction of bedding and igneous appearance of the rock caused by the metamorphism. On the floor of the small "water fall" (by red flag) a small dike of dacite porphyry can be seen cutting the sediments.

Up stream several yards, at the next red flag, an outcrop which shows definite bedding can be seen. Still further up-stream the contact with the aparently conformable, overlying Silver Bell complex andesite breccia may be seen.

Stop 8A.

Here some members of the party may want to take the alternate route (dashed line on the map) to see a larger but less well exposed ignimbrite feeder dike. The dike cuts the Silver Bell complex and shows vertical, north trending eutaxitic texture. At the base of the extrusive ignimbrite which caps the mountain the eutaxitic texture turns abruptly and strikes east-west with a steep northerly dip.

Stop 8B.

Walking up the saddle we cross a sill of ignimbrite (cliff forming outcrop) which intrudes the Silver Bell complex andesite breccia. At the top of the saddle (near the red and yellow flagging) a dikelet of intrusive ignimbrite can be seen cutting the Silver Bell complex. To the north the dike narrows and dies out, the igneous nature of the contact being clearly seen. To the south the dike flattens to a sill-like body with a dip of 23 degrees east-southeast.

The party will continue to the south east along the contact of the ignimbrite sill and the Silver Bell complex. In two or more places ignimbrite of the sill can be seen welling up around fragments of andesite porphyry from the overlying Silver Bell complex. A few yards up the side of the hill (to the east) the contact of the Silver Bell complex and the overlying extrusive ignimbrite can be seen.

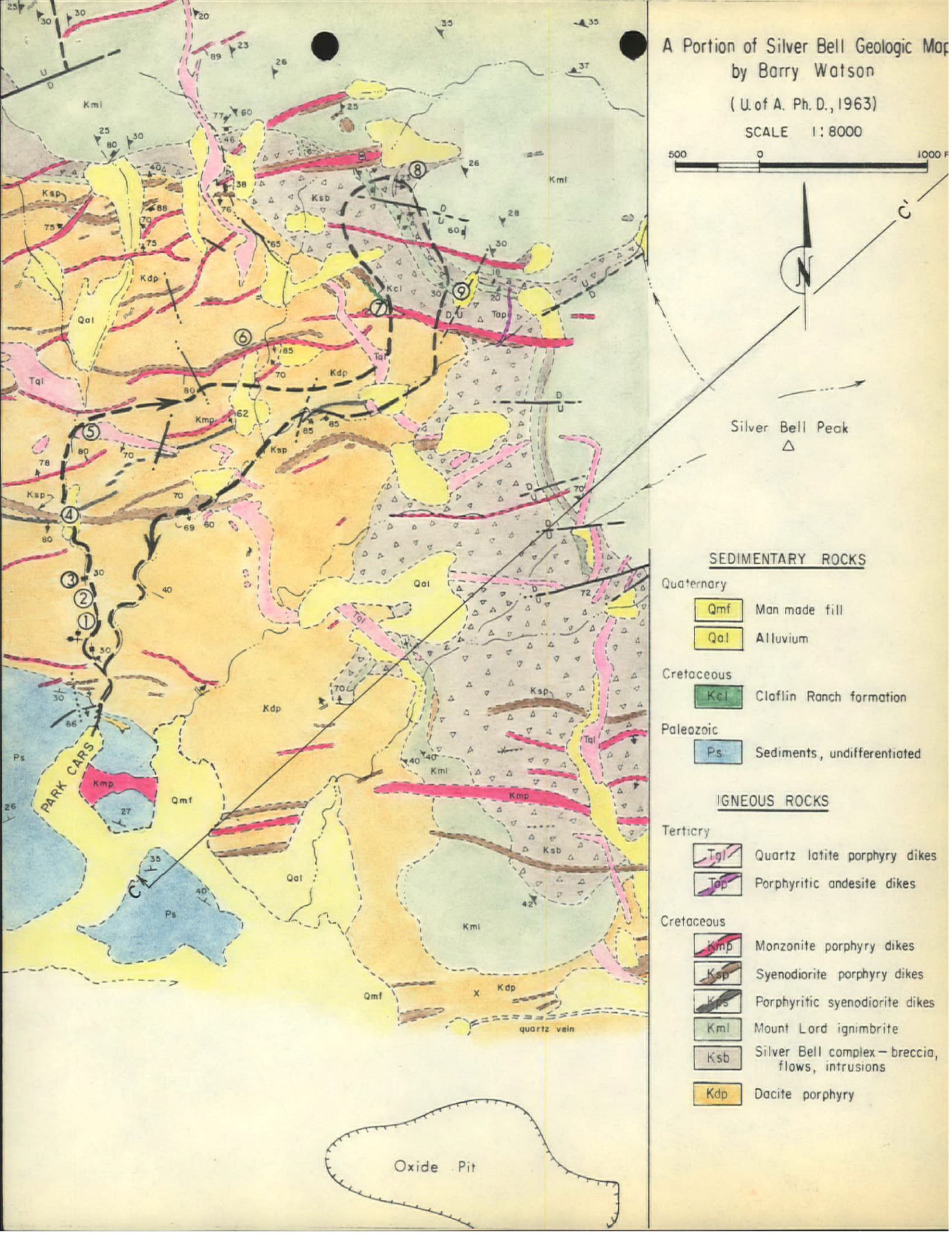
Stop 9.

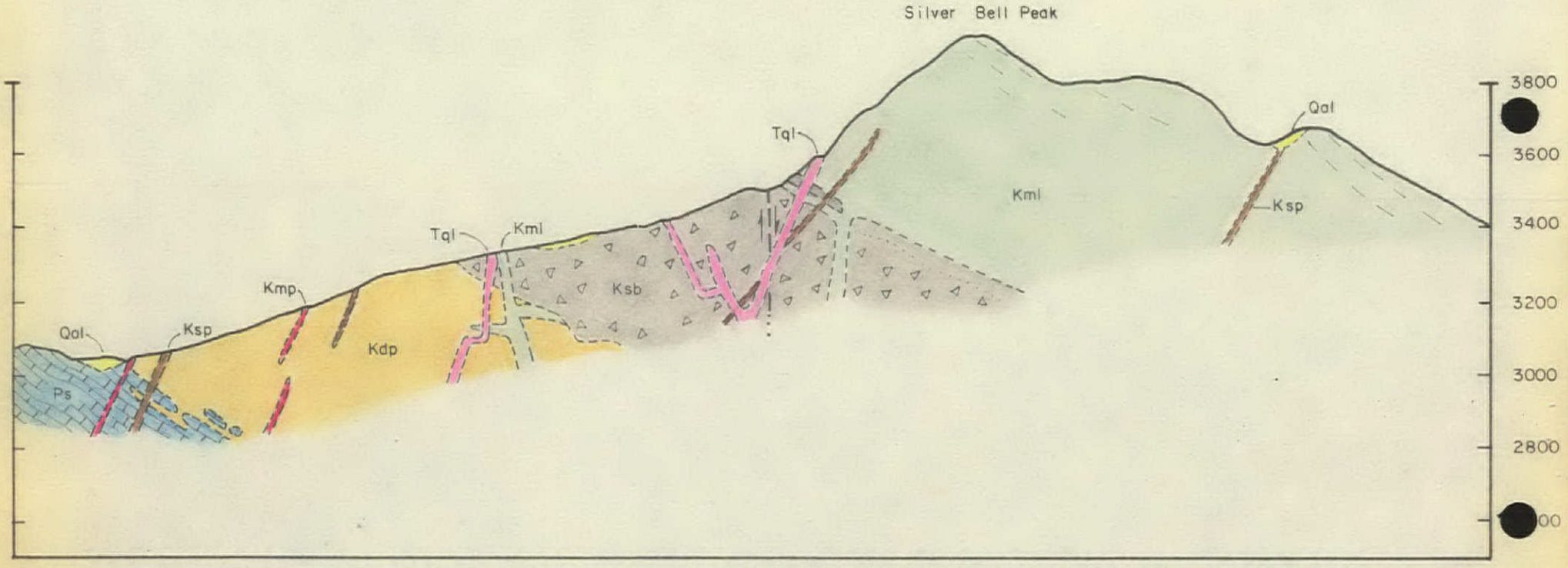
Here the basal contact of the ignimbrite sill and the Silver Bell complex can be seen. A few feet below the sill a small "feeder" dike of intrusive ignimbrite cuts the Silver Bell complex.

Stop 10.

After walking down-section through the Silver Bell complex we again see the gradational contact between the dacite porphyry and the Claflin Ranch sediments. At the red flag, under the palo verde, a small patch of distinct bedding can be seen in an outcrop that is otherwise almost indistinguishable from dacite porphyry. A series of thin sections cut from similar outcrops show no distinguishable change in texture to delineate the dacite from the metasediments of the Claflin Ranch formation.

From Stop 10 the party will continue down the main drainage through dacite porphyry cut by dikes of Tertiary quartz latite and Cretaceous syenodiorite porphyry, and return to the cars.


A Portion of Silver Bell Geologic Map
by Barry Watson
(U. of A. Ph. D., 1963)
SCALE 1:8000
500
0
1000 F
N
C'
Silver Bell Peak
SEDIMENTARY ROCKS
Quaternary
Qmf Man made fill
Qal Alluvium
Cretaceous
Kcl Claflin Ranch formation
Paleozoic
Ps Sediments, undifferentiated
IGNEOUS ROCKS
Terticry
Tql Quartz latite porphyry dikes
Tap Porphyritic andesite dikes
Cretaceous
Kmp Monzonite porphyry dikes
Ksp Syenodiorite porphyry dikes
Kps Porphyritic syenodiorite dikes
Kml Mount Lord ignimbrite
Ksb Silver Bell complex — breccia, flows, intrusions
Kdp Dacite porphyry
PARK CARS
quartz vein
Oxide Pit



GEOLOGIC SECTION C-C′, SILVER BELL MOUNTAINS

Looking Northwest

Scale 1:8000 Vertical Exaggeration X 1.67

Copied from B. Watson, U. of A. Ph. D., 1963

J.H.C.

APR 15 1969

AMERICAN SMELTING AND REFINING COMPANY
Tucson Arizona

April 15, 1969

FILE MEMORANDUM

TO: J.E. Kinnison
S.R. Davis
B.E. Kilpatrick
R.D. Karvinen
Bob Rawlins - (Hold for arrival, April 20)

Porphyry Copper Tour

Tuesday, April 22

Visit Sunnyside and Turquoise - Lodge at Bisbee.

Wednesday, April 23

Keith Coke, Geologist, Phelps Dodge

Arrive 7 A.M. at General Office, underground tour (purchase rubber underground boots in Tucson). P.M. pit tour.

Thursday, April 24

Visit area north of Lavender Pit - (mineralized porphyry pebbles in Glance) - Continue to Safford, then to Morenci - Chase Cr. Canyon tour.

Friday, April 25

Arrive at Main Office 8:00 A.M. - (Dick Moolick or Joe Dureck, Chief Geologist) - Visit pit. Lunch, then return to Tucson via Safford, Globe, Superior, Ray, San Manuel.

Saturday, April 26

Field trip to Silver Bell Mts. - Leave ASARCO parking lot 7:30 A.M.

J.H. Courtright
J.H. Courtright

JHC:lzb

cc: WESaegart
SIBowditch

ROAD LOG
WEST SILVER BELL MOUNTAINS
1969 AGS Spring Field Trip

Meeting begins at ASARCO parking lot, 1150 N. 7th Avenue. Caravan will take Speedway west to the freeway (Casa Grande Highway) and travel north. Log begins at the Ruthrauff Rd. overpass. Truck stop complex on the right.

Total Miles	Interval	Road Log
0	0	Ruthrauff road overpass.
1.1	1.1	Orange Grove Rd. Amole Peak at 9 o'clock is the high point in the Tucson Mountains.
5.8	4.7	Cortaro Rd. overpass. Safford Peak at 9 o'clock, is a dacite neck. The low ridges on the left are mid-Tertiary volcanics. Picacho Peak is dead ahead on the skyline (visible unless smog is unusually heavy)
8.1	2.3	Prepare to take right hand ramp off freeway at Avra Valley Rd., exit 1 mile. Move to right hand lane.
9.1	1.0	Exit.
9.3	0.2	STOP. Turn left. Rd. sign points to RILLITO.
9.4	0.1	DO NOT turn right at sign RILLITO. Continue
9.5	0.1	Small sign on the left directs to ASARCO, SILVER BELL--23 miles. Follow this paved road.
9.8	0.3	Crossing north tip of the Tucson Mountains. Bridge crosses Santa Cruz River.
10.5	0.7	Road cut in mid-Tertiary andesite.
10.6	0.1	TRUCK CROSSING, CAUTION. Arizona Cement Company plant at 3 o'clock; limestone quarry at 9 o'clock is an outlier of Paleozoic strata, known as Twin Peaks or (older ref.) Picacho de Calera.
10.8	0.2	At 9 o'clock: Looking south into Safford Peak, a volcanic neck intrusive into gently dipping mid-Tertiary volcanics. The horizontal strip of white visible ahead just below the skyline is the Silver Bell tailing pond.
12.6	1.8	At 9 o'clock, Twin Peaks and a low hill to the north, both Paleozoic limestone outliers. Ahead on the skyline, the Silver Bell tailings pond is in a narrow valley basin between the Silver Bell Mountains on the north and the Waterman Mountains on the south. The high peaks in the Central Silver Bell Mountains are formed of Laramide ignimbrite; the jagged peak to the north is Ragged Top, an eroded mid-Tertiary plug. To the southwest, about 10 o'clock, Kitt Peak on the skyline, as is Baboquivari Peak about 9 o'clock. The low range in view on the southwest is the Roskruge Mountains, of Laramide volcanics.

ROAD LOG

Total miles	Interval	
14.8	2.2	Crossing Avra Valley--good farm land.
19.3	4.5	Your car is pointed at the Silver Bell tailings pond. Ragged Top on the skyline at 1 o'clock. The Sasco Hills at 2 o'clock form the low skyline. Picacho Peak and Picacho Mountains are at 3 o'clock.
23.8	4.5	Low hills nearby on the right are post-mineral, mid-Tertiary andesites. A conglomerate beneath the flows contains altered porphyry fragments with cavities derived from leached sulphides.
27.6	3.8	Enter a slightly trenched pediment carved on tilted Cretaceous (?) Clastic sediments.
28.5	0.9	Tin Buildings in a little saddle at 10 o'clock, with the narrow road leading up to them, mark the Indiana Mine, a lead-zinc replacement in Paleozoic limestone. The limestone bluffs on the left form the north edge of the Waterman Mountains.
29.0	0.5	Titan Missle site at 9 o'clock.
30.2	1.2	Tailings pond on the right.
30.8	0.6	Road swings northerly toward Silver Bell camp. Brown colors in the foreground hills indicate a pervasively mineralized zone of igneous rocks. The hump-back hill at 1 o'clock is Portland Ridge--possibly an intrusive ignimbrite; Silver Bell Mill is at its base.
31.6	0.8	Residence area on the left. Mine offices are ahead.
31.7	0.1	Slow, 15 mph. Turn left at the speed limit sign.
31.8	0.1	Swing around the loop and enter the paved road going south.
31.85	0.05	Cattle guard. You have gone too far. Back up 100 feet and turn right on a graded dirt road, a part of the old Silver Bell road maintained by Pima County. Please do not get lost here.
31.9	0.05	Turn sharp left and follow the graded road.
32.2	0.3	Cretaceous red beds.
32.3	0.1	Corrals and ranch house.
32.6	0.3	Leaching plant at 3 o'clock. Altered igneous hills at 1-2 o'clock.
32.8	0.2	Weak alteration of K? sediments.
34.4	1.6	From the last point the road has run parallel and slightly west of the limits of pervasively mineralized zone.
34.9	0.5	From last point road is on weakly altered and mineralized igneous rock.
35.1	0.2	Old smelter slag dump.
36.0	0.9	Point of dump by road. From last point road has crossed streaks of very weak mineralization. The main zone of pervasive mineralization is to the east.

ROAD LOG

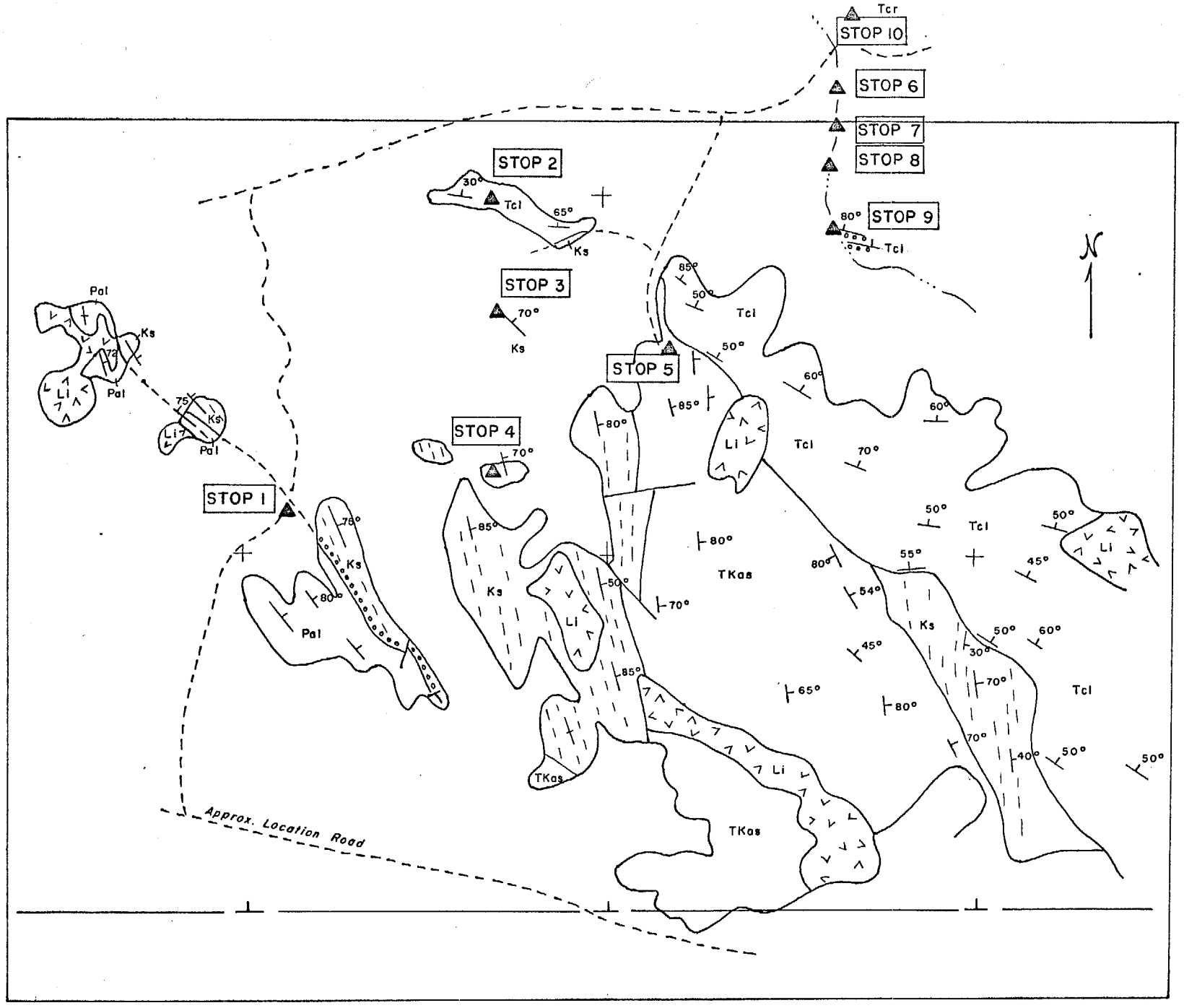
Total Miles	Interval	
36.3	0.3	Road enters unaltered igneous rock.
36.8	0.5	Cattle guard. Atlas Mine (lead-zinc replacement) at 2 o'clock.
37.2	0.4	County road curves right. Take left fork.
37.8	0.6	Cross road, turn left.
37.9	0.1	Graveyard.
38.0	0.1	Take left fork.
38.8	0.8	Road leading north. Continue straight.
40.0	1.2	Fence and gate. Continue ahead.
40.3	0.3	Fence and gate. Enter Papago Indian Reservation (SW Cor.Sec 31, T11S,R8E).
41.0	0.7	Sharp ridge of Claflin Ranch formation, at 3 o'clock, dips 30°E.
41.7	0.7	Low hilss of andesite and Cretaceous sediments.
42.1	0.4	Road leads north to Gato Peak. Continue ahead.
42.3	0.2	Take right fork.
42.5	0.2	Cretaceous sediments on the right. Paleozoic limestone makes sharp gray ridges ahead.
42.6	0.1	Take left fork, along power line.
42.8	0.2	Paleozoic limestone, dips east, on ridges ahead.
43.2	0.4	Take road leading north (to the right).
43.5	0.3	Take right fork.
43.7	0.2	Stop 1. Hike about 400 yards up to Cretaceous-Paleozoic contact. A basal conglomerate is present, overlain by arkoses and siltstone of presumed Cretaceous age. The lithology is similar to that of the Amole Arkose in the Tucson Mountains. From Stop 1 drive northerly following bulldozer road and tire tracks overland as required.
44.9	1.2	Desert Auto road crosses bulldozer trail. Turn right.
45.5	0.6	Gato Peak at 1 o'clock, Claflin Ranch fm, dips NE. Sharp peak of K sediments, at 3 o'clock, dips steeply NE. Ahead, Ridges and Peaks formed from Silver Bell and Claflin Ranch formations. Begin detour to stops 2, 3, and 4. Take bulldozer road south (turn right).
45.8	0.3	Stop 2. Claflin Ranch formation. Isolated outcrop of grits and siltstone, dipping 40°NNE. Ignimbrite at this stop might be intrusive.
46.1	0.3	Stop 3 (brief) Small exposure isolated in alluvium. Ledge of typical limy grit and conglomerate of the Cretaceous section. Dips 70°NE.

ROAD LOG

Total Miles	Interval	
46.5	0.4	Stop 4. Hike east, down slope and cross small wash onto next ridge, about 300 yards. Cross steeply inclined strata typical of the Cretaceous section. Thin beds of argillite and sandstone, and some thin silty limestone. All slightly metamorphosed. Return to beginning of detour. Turn right, and continue on desert auto road.
48.0	1.5	Begin detour to Stop 5. Take cross road right 0.8 miles to southern base of Gato Peak. Do not take any left hand forks.
48.8	0.8	Stop 5. Claflin Ranch formation forms the resistant ledges of Gato Peak, overlying the andesite conglomerate and/or flows, and/or intrusive andesite. The attitude which can be seen in a few places is parallel to the Cretaceous strata on each side of this andesitic complex, and is markedly divergent from the attitude of the overlying conglomerates of the Claflin Ranch. We interpret the contact as an unconformity possibly equivalent to the Tucson surface in the Tucson Mountains. Refer to the geologic sketch map for better visualization of structural relationships.
49.6	0.8	Return to beginning of detour, turn right and continue on desert auto road.
49.7	0.1	Abandoned windmill.
50.0	0.3	Large wash. Drive or walk south toward stops 6, 7, 8, and 9.
50.1	0.1	Stop 6. Cat Mountain rhyolite; Dips 15° NE. Laramide welded ignimbrite.
50.2	0.1	Stop 7. Arkose with a few pebbles. This could mark the erosion surface present in some localities at the base of the Cat Mountain (as in the Roskruge Mountains).
50.3	0.1	Stop 8. Andesite. This does not display the typical laharic breccia texture of the Silver Bell formation, but is probably more or less equivalent to that formation (Note: if Caravan drives down the wash, turn around at stop 8).
50.5	0.2	Stop 9. Sandstone and andesite-conglomerate of the Claflin Ranch formation underlie andesite breccia of the Silver Bell formation. The length of time at this stop will depend partly on the temperature and general state of decay of the dead cow in the pothole at the contact above described.
51.0	0.5	Return to detour point and continue.
51.1	0.1	Stop 10. Walk east up slope for outcrops of Cat Mountain rhyolite. Begin return route, crossing the northern part of the Silver Bell Mts.
51.6	0.5	Cattle guard.
52.2	0.6	Take road leading east (right). Before turning, pre-Cambrian granite ridge forms skyline at 10 o'clock.
52.3	0.1	The black mesa ahead is Mid-Tertiary basalt.
53.3	1.0	Crossing the point of a ridge of mid-Tertiary basalt.

ROAD LOG

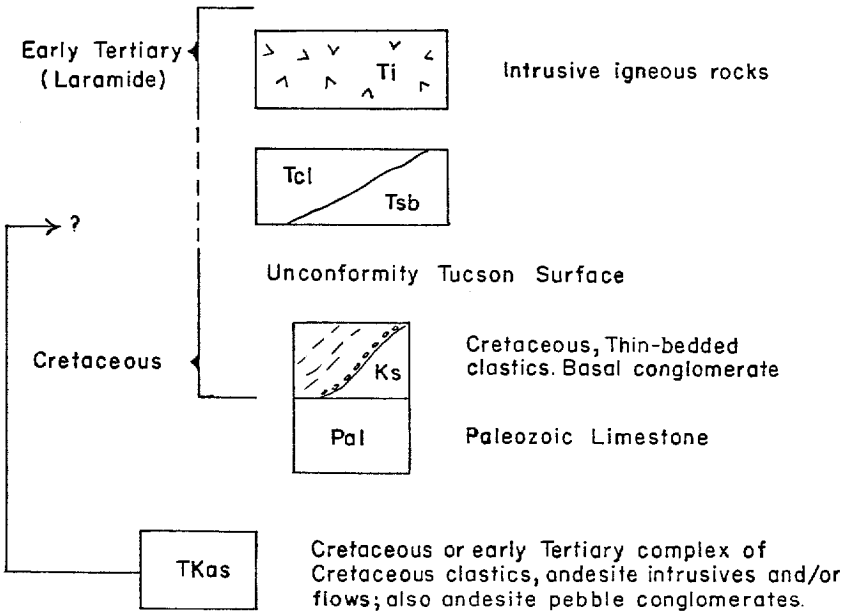
Total Miles	Interval	
53.4	0.1	Connection with desert road, turn left.
53.9	0.5	Turn right on road, along fence.
54.1	0.2	Take right fork.
54.9	0.8	Turn right, then left and pass through gate on a road crossing easterly.
56.2	1.3	Light tan rock on lower slope of Mesa, at 10 o'clock, is pre-Cambrian granite which lies beneath the basalt flow.
57.6	1.4	Cattle guard. Turn left on the old Silver Bell road. Before turning, Ragged Top is at 1 o'clock. The mid-Tertiary volcanic-textured plug intrudes along a fault, striking WNW, which brings pre-Cambrian granite on the north against Laramide volcanics on the south.
59.9	2.3	Left bend in road. The straight, even line of the road ahead is because the road is built on the old railroad grade which connected the Sasco Smelter with the Imperial Copper Company mines at Silver Bell.
60.0	0.1	Turn right and return on the Cocio Ranch road. Note: This turn off is easily passed up as the road is shielded from view by brush.
61.5	1.5	Ragged Top at 3 o'clock.
63.1	1.6	Pediment cut on crumbly pre-Cambrian granite.
63.6	0.5	El Paso gas line.
66.5	2.9	Entering alluvial slope to the Santa Cruz drainage. Post-mineral volcanic hills (Sasco Hills) are to the north; an isolated volcanic knob is to the south.
72.2	5.7	Connection with road crossing. Turn right.
74.6	2.4	Trico Compressor Plant.
79.2	4.6	Connection with cross road. Turn right.
79.7	0.5	Connection with Avra Valley road. Turn left.
85.9	6.2	Casa Grande Highway (freeway). Turn right and return to Tucson.
		NOTE: Alternate route through Red Rock to Tucson. Continue past 60.0 mileage at Cocio Ranch road.
62.1	2.1	Pre-Cambrian granite on the right. Sasco Hills immediately ahead, made of mid-Tertiary volcanics and conglomerate.
65.4	3.3	Ruins of Sasco camp on the right.
65.7	0.3	Ruins of Sasco Smelter on the left.
67.6	1.9	Santa Cruz River (with water, too!)
72.7	5.1	Red Rock. Turn right to connect with Casa Grande Highway to Tucson.



GEOLOGIC MAP
WEST SILVER BELL MTS.

Mod. from Craig W. Clarke,
1965, Pl. 6. Univ. Ariz. Thesis.

Generalized Columnar Section
West Silver Bell Mountains



for A.G.S. Spring Field Trip
1969

J.H.C
MAR 12 1969

AMERICAN SMELTING AND REFINING COMPANY
Tucson Arizona

March 12, 1969

TO: J.H. Courtright

FROM: J.E. Kinnison

AGS Field Trip

Bill Lumby of Austral Oil (623-6331 in Tucson) gave permission to use their access roads in the West Silver Bell Mountains.

John E. Kinnison
J.E. Kinnison

JEK:lzb

file "field trips"

IN REPLY REFER TO:

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
FEDERAL CENTER, DENVER 25, COLORADO

December 26, 1967

J. H. C.

JAN 8 - 1968

READ AND RETURN ✓
PREPARE ANSWERS ____ HANDLE ____
FILE ____ INITIALS ____

Mr. J. H. Courtright
P. O. Box 5795
Tucson, Arizona 85703

Dear Mr. Courtright,

We had promised David Lowell to keep you informed of our plans for the field trip in the northern Santa Rita Mts.

The enclosed copies of the map and road log, now in David Lowell's hands, will show you our general intentions. Although our schedule is fairly full, we should be able to find time at appropriate stops, for a few short oral contributions from informed trip participants. Your wide knowledge of the region suggests that our participants would certainly benefit from any discussion you may wish to prepare. Naturally, any informal participation would always be welcome, too, and may serve to present alternatives we've overlooked.

I look forward to returning to Tucson by March 1st.

Have a Happy New Year.

Sincerely,

Harald Drewes

Harald Drewes

Enclosure

Copy to J. David Lowell

JDS

Revision after April correction

TDS

READ AND RETURN ✓

PREPARE ANSWERS ____ HANDLE ____

FILE ____ INITIALS ____

J. H. C.

JAN 8 – 1968

Field Trip

for

Cordilleran Section G.S.A. Meeting

in

Tucson, April, 1968

Mesozoic stratigraphy and Laramide tectonics of

part of the Santa Rita and Empire Mountains,

southeast of Tucson, Arizona

by

Harald Drewes and Tommy L. Finnell

Introduction

The Santa Rita and Empire Mountains are the nearest ranges southeast of Tucson; their northernmost ends lie only 20 miles away. Much of the geology in this area is typical of a larger region lying roughly between Tucson, Nogales, Benson, and Bisbee, in which the U. S. Geological Survey has almost completed a series of detailed maps and related stratigraphic and structural studies during the last 8 years. J. R. Cooper, S. C. Creasey, P. T. Hayes, R. B. Raup, Jr., F. S. Simons, and the present authors have been, or are still, engaged in this work.

This field trip is planned to illustrate two of the more important geologic features, whose recognitions are results of this work: (1) a relatively complete Mesozoic stratigraphy, and (2) a complex 3-phase deformation during the Laramide orogeny. Although not all areas investigated include a fully developed Mesozoic sequence or evidence of the entire Laramide history, most areas contain some parts of the sequence or some aspects of this history. In a few areas that will not be visited on this field trip because of the greater distance from Tucson, certain rocks or structural relations are even more clearly illustrated than they are in the northern Santa Rita and Empire Mountains.

Geology

In brief, the geologic record of the region begins with Precambrian Pinal Schist into which coarsely porphyritic granitic rocks were intruded. During Paleozoic time about 5,000 feet of marine sediments were deposited discontinuously. The largest disconformities in this sequence occur between Cambrian and Devonian strata, between Devonian and Mississippian strata, and between Mississippian and Pennsylvanian strata. By the middle of the Permian the seas had left the area.

During the Triassic and possibly also parts of the Permian and Jurassic a thick pile of rhyolitic and dacitic volcanics were deposited in a subaerial environment. The volcanics contain intercalated conglomerate and eolian sandstone, and are associated with red beds. More rhyolitic tuff overlies the red beds. The age of these rocks is obtained from radiometric determinations and is supported by geologic relations to other dated rocks. During Late(?) Triassic time a monzonite pluton was emplaced and during Middle Jurassic time several major granite plutons were also emplaced. The earliest hints of post-Paleozoic faulting go back to this interval.

During latest Jurassic or earliest Cretaceous time the region was strongly uplifted. Rhyolitic to dacitic volcanic rocks were deposited in several ranges, and on them sedimentary rocks many thousands of feet thick were deposited in much of the region during the late Early Cretaceous; most widespread and best dated of these deposits is the Bisbee Formation (Bisbee Group to the southeast).

During early Late Cretaceous we find the earliest signs of the first phase of the Laramide orogeny in the form of a major unconformity in the sedimentary record, and of northeast-southwest-directed compression and locally, at least, thrust faults in the tectonic record. During the late Late Cretaceous many more thousands of feet of sedimentary rocks were deposited, apparently in local basins. These rocks are also folded by northeast-southwest compression, providing the latest signs of the first phase of the orogeny. Toward the end of the Late Cretaceous dacitic breccia and rhyodacitic welded tuff were spread, apparently from several centers, as forerunners of the major magmatic activity that followed. All the present ranges received some plutonic intrusions of granitic rocks during the next phase (or phases) of the Laramide and in some ranges there are numerous stocks and many rock types represented. In most ranges, too, thrusting, normal faulting and tear faulting occurred during the end of the Cretaceous and the beginning of the Tertiary.

In the northern Santa Rita Mountains the geologic record also permits a distinction between a second and a third phase of the Laramide orogeny, both involving northwest-directed tear and thrust faulting. Quartz monzonite plutons were injected between these phases and quartz latite porphyry were intruded after the third phase, so that these phases are datable by radiometric means.

During the field trip we will stop at outcrops representative of the major groups of Mesozoic volcanics and sedimentary rocks: The Triassic volcanics, the red beds associated with them, the Bisbee Formation, the Upper Cretaceous sedimentary rocks, and the uppermost Cretaceous volcanics. We will also stop to see evidence of northeast-directed deformation and the evidence to separate the second from the third phase involving northwest-directed tear and thrust faults. The map pattern of folds in the Lower Cretaceous rocks truncated by unconformably overlying uppermost Cretaceous rocks and the change in the stress picture between phase 1 and 2 must suffice to demonstrate their temporal separation for outcrops demonstrating the early Late Cretaceous unconformity are not accessible by bus.

Road Log

Leave Tucson, driving east on Interstate Highway 10. Road log begins at junction of Highway 10 with State Highway 83. Figure 1 shows route of field trip and general geology.

Figure 1. Near here

Segmental mileage	Cumulative mileage	
0.0	0.0	Junction. TURN RIGHT (S) on State Highway 83, toward Sonoita. Empire Mountains on the left (E) are made up of Paleozoic and Mesozoic sedimentary rocks in a complexly faulted anticline. The core of the anticline is composed of a quartz monzonite stock of Laramide(?) age, which cuts across the Empire thrust fault along the western flank of the mountains. Mt. Fagan, at the north end of the Santa Rita Mountains, on the right (W) consists of Upper Cretaceous dacitic and rhyodacitic volcanic rocks that rest with angular discordance upon folded sedimentary rocks of the Bisbee Formation. In the valley between the Santa Rita and Empire Mountains the Upper Cretaceous volcanic rocks lap across the Empire thrust fault.

Figure 1.--Generalized geologic map of part of the Santa Rita and Empire Mountains southeast of Tucson, Arizona. Field trip route shown by road in solid lines; field trip stops shown by heavy numbers.

1.6	1.6	Roadcuts on right (W) in quartz monzonite of probable early Tertiary age, overlapped to the south by gravel of Tertiary or Quaternary age.
0.5	2.1	Bluffs to left (E) across wash are sedimentary rocks of the Bisbee Formation. In Davidson Canyon, about a mile to the east, these sediments rest unconformably upon diorite gneiss of Precambrian(?) age.
1.4	3.5	Roadcuts in south-dipping rocks of the Bisbee Formation. Hill at 1:00 is part of a west-northwest trending syncline in quartzites of the Bisbee Formation. Low hill at 11:30 is Permian Concha Limestone and Rainvalley Formation in upper plate of the Empire thrust fault.
0.9	4.4	Enter area shown on figure 1.
1.6	5.1	Empire thrust fault is here concealed. Permian limestone in upper plate strikes north and dips 20° E. Bisbee sedimentary rocks in lower plate strike west and dip steeply north.
0.6	5.7	SLOW for sharp turn to left off highway.

0.1	5.8	Turn left (E) onto old highway and proceed 0.5 mile to STOP 1.

Hills on right (E) side of road are capped by Glance(?) equivalent that is cut by a dike of quartz latite porphyry.

STOP 1. Sedimentary rocks of probable Triassic age are exposed in roadcuts and in the slopes leading down to the arroyo to the west. They rest on the Rainvalley Formation (Permian) that forms the dip slope of the hill west of the arroyo, and they are overlain by limestone pebble conglomerate that is probably correlative to the Glance Conglomerate. Uplift, faulting, and erosion preceded deposition of the Glance(?) in the area so that only about 250 feet of the Triassic(?) sedimentary rocks remain. About a mile east-northeast, a thicker section is exposed that includes some latitic tuff in the upper part.

If the bus cannot turn around at this stop, it may proceed 0.4 mile to borrow pit on left, turn around, and return to pick up party at STOP 1. Return to Highway 83 and STOP 2.
(Road log mileage does not include detour for STOP 1.)

STOP 2. Roadcuts in shaly rocks of the Bisbee Formation and conglomeratic mudstone of Triassic(?) age. The Empire thrust fault zone between them dips 5-10° E. Rhyolitic dikes with conspicuous flow banding seem to cut the fault zone.

0.2	6.0	Pediment gravel to left (E) across Davidson Canyon rests on eroded surface of quartz monzonite. Foothills of Empire Mountains are synclinal roof pendants of Paleozoic and Mesozoic sedimentary rocks. Hill at 12:00, west of road, is Scherrer Formation (Permian) in the west limb of the syncline. Mesozoic sediments form ridge east of road.
1.1	7.1	Quartz monzonite beneath gravel in roadcut appears to underlie the Scherrer Formation at 1:00.

0.3	7.4	Prospect pit at 2:30 is in carbonates of the middle member of the Scherrer Formation. The contact with quartz monzonite is a few feet below the prospect. Roadcuts ahead are in a complex of quartz monzonite, quartz latite porphyry, and rhyolite. They contain some inclusions of hornfelsed sedimentary rocks of uncertain age.
0.2	7.6	Dike of quartz latite strikes northwest, and dips 70° SW. The westerly trending ridges at 2:00 are formed of quartzite beds in the Bisbee Formation, which form an isoclinal syncline overturned to the south. The axial plane of the syncline dips about 55° N.

For the next 3 miles, the bedrock near the road is of sedimentary and volcanic breccias of intermediate composition of Late Cretaceous age. Some rhyolitic dikes of Tertiary age cut them.

1.4	9.0	STOP 3 (Optional). Park on left (E) at entrance to ranch road. Cuts expose volcanic conglomerate of Late Cretaceous age. Clasts in the conglomerate include sandstone and siltstone derived from the Bisbee Formation.
1.5	10.5	Pantano(?) Formation of mid-Tertiary age of Brennan, 1962, on west side of road, faulted against the Upper Cretaceous volcanic rocks. Exposures from here to STOP 4 are of the Pantano(?) Formation.
1.0	11.5	Road to Rosemont on right. Dumps of the Rosemont mining district at 2:30 near crest of ridge.
0.2	11.7	Mid-Tertiary conglomerate along road to STOP 4.
0.6	12.3	STOP 4. Unconformable contact of Pliocene and Pleistocene gravel on conglomerate of the mid-Tertiary Pantano(?) Formation.

Panorama of the south end of the Empire Mountains to the east across Davidson Canyon. Sediments of the lower part of the Bisbee Formation dip as much as 60° southeast and south in the allochthonous block of the Empire thrust fault. Between the vantage point and Davidson Canyon sedimentary rocks of the upper part of the Bisbee Formation dip as much as 50° E in the autochthonous block. Upper Cretaceous volcanic breccia laps across the Empire thrust fault and rests unconformably on the upturned and eroded Bisbee Formation of both blocks, indicating that the Late Cretaceous volcanism occurred after the displacement of the Empire thrust fault. Escarpment to south is eroded in Pliocene and Pleistocene gravels that are well-exposed along the road for the next 2 miles. The beds dip as much as 10° SE.

4.7	16.8	Turn right (SW) onto Greaterville and Box Canyon road.
.4	17.2	Turn right (W) at junction, keeping on main road.
1.6	18.8	Slow for Thurber Ranch.

1.3	20.1	Turn right (NW) at Greaterville junction, keeping on Box Canyon road.
1.4	21.5	Outcrops to left (SW) are of Pliocene and Pleistocene gravel, slightly tilted eastward past their initial dip.
.4	21.9	STOP 5. Bisbee Formation Glance Conglomerate, in a limestone pebble facies, crops out south of the wash. Maroon siltstone and arkosic sandstone of the Morita(?) equivalent (Willow Canyon Formation of the Bisbee Group of Tyrrell, 1962) dip eastward in roadcuts to the west. Instead of underlying the Morita(?) as is normal, the Glance(?) equivalent is thrust over that formation, where it dips westward. Small slivers of Devonian Martin Formation (not shown on generalized geologic map) are caught along the thrust fault. One such sliver is exposed low on the slope north of the road. Half a mile to the north, Mississippian Escabrosa Limestone lies along the thrust fault. The normal fault between the probable Glance and the Pliocene and Pleistocene gravel to the east is exposed in a small prospect north of the road. See sections A-A' and B-B' of figure 2.

Figure 2. Near here

.7 22.6 STOP 6. Bisbee Formation and Precambrian granodiorite. Series of roadcuts from east to west shows, respectively: (a) Morita(?) equivalent) (Willow Canyon Formation of Tyrrell (1964)) red siltstone and light-gray arkosic grit and sandstone, grading downward into (b) arkose, arkosic conglomerate, and arkosic sedimentary breccia facies of the Glance(?) equivalent and (c) granodiorite source rock of the arkose. Faulting near the base of the Glance is minor and the slice of Cambrian Bolsa Quartzite between the granodiorite and the arkosic conglomerate exposed south of the canyon is probably nearly in place as an erosional remnant beneath the pre-Bisbee unconformity. A half mile north of the road there is a large body of Bolsa Quartzite and the overlying Cambrian Abrigo Formation in a similar position between granodiorite and Glance(?). The rapid change in facies of the Glance(?) between STOPS 1 and 2 may be partly due to tectonic telescoping, but it may also be rapid initial changes that reflect local deposition around hills of pre-Bisbee age of various provenance.

Figure 2.--Diagrammatic structure sections in area shown on figure 1. A-A' and B-B' along Box Canyon, C-C' and D-D' at Helvetia show approximate endpoints of sections.

The age of the granodiorite has been interpreted from field evidence either as Jurassic or as Precambrian. Geologic relations used to infer a Jurassic (specifically a post-Paleozoic--pre-Early Cretaceous) age occur 2 1/2 miles north of Box Canyon, where there is a peculiar mixture of granodiorite and Bolsa Quartzite, a mixture suggestive of flowage of the granodiorite into the quartzite, but presently interpreted as a flowage of remobilized quartzite into the granodiorite. In most places, moreover, the basal part of the Bolsa, a 25-foot thick conglomerate, is present and is parallel to the basal contact. The shearing that does occur along that contact is probably minor south of the complexly deformed area around Helvetia and need only reflect local adjustment as the rocks were tilted and minor thrusting where the overlying Bisbee is folded. About 1 1/4 miles north of STOP 6 some of this shearing may even have predated the deposition of the Bisbee Formation.

Radiometric dates of the granodiorite include:

Pb-alpha	(zircon)	1450 m.y.
Sr-Rb	(whole rock)	800 m.y.
K-Ar	(biotite)	55.5 m.y.

These dates are interpreted to mean that the rock was initially crystallized during the Precambrian but that reheating of some rock during the Laramide recrystallized the biotite. Recrystallization of biotite is verified under the microscope.

.6 23.2 Red beds of the Bisbee Formation appear along the road in a graben in the granodiorite. A component of tear faulting is suspected along the bounding faults but can not be unequivocally determined.

.4 23.6 Precambrian granodiorite 200 feet southeast of dry(?) waterfall was sampled for Pb-alpha and Sr-Rb radiometric dates. A thick northeast-trending rhyolite porphyry dike lies north of the road a few hundred yards west of the fall, and a thin quartz latite porphyry dike an additional few hundred yards west of the rhyolite dike.

.7	24.3	Two dikes of rhyolite porphyry (Pb-alpha, 40 m.y.; K-Ar, 26 m.y.) are part of a swarm of dikes that fill post-Laramide tension fractures. In the southern part of the Santa Rita Mountains a mineralized quartz vein swarm fills this fracture system. The rhyolite porphyry dikes cut a quartz latite porphyry dike exposed near the switchback 0.1 mile farther west and is again exposed downhill (W) of the switchback. These dikes form part of an older group, some of which are shoots of the late Laramide quartz latite porphyry plutons.
1.0	25.3	Precambrian granodiorite a few hundred yards below the switchback provides datable biotite (K-Ar, 55.5 m.y., probably a recrystallization age).
.2	25.5	Turn left (SW) toward Madera Canyon and Continental.

2.4	27.9	Spur to left (SE) is underlain by Pinal Schist intruded by the Precambrian granodiorite. Small white cut on far side of wash about 1/4 mile south of the road exposes a gouge consisting of schist to the east and of the oldest local gravel (Pliocene and Pleistocene) to the west. Nearby, this gravel dips as much as 15° into the range. Similar young range-front faults appear along northeast-trending segments of the Santa Rita and Patagonia Mountains.
.8	28.7	Sharp turn to left (SE) just past the wash of Sawmill Canyon.

.7 29.4 STOP 7. Low road cuts expose reddish-gray sandstone, conglomerate, and siltstone of the Upper Cretaceous sedimentary rocks. These lie along the Sawmill Canyon fault zone, which trends southeastward across the range and contains numerous slices of Paleozoic rocks. The nearest small slice of Paleozoic rock lies on the low hill half a mile to the southeast; farther southeast the Paleozoic slices become more numerous and larger, and the stratigraphic sequence of individual fault slices is more complete. The fault zone has had a long and complex history, possibly beginning during Triassic time, and certainly involving movement during early Late Cretaceous and early Tertiary, but ending before the close of the Oligocene. Much movement need only have been vertical but some early thrust faulting occurred, and lateral displacement may also be significant, but has not been conclusively demonstrated.

Walk west to low hill. Bus continues, empty, to the sharp junction, turning right (W). It may be necessary for the bus to turn at the entrance to the corral another .4 mile up the road and then to return to the junction, now turning left (W) toward Continental.

.5 29.9 Road log mileage measurements continue to the sharp junction, and beyond the junction to pickup area but do not include the distance to corral and back.

.5 30.4 STOP 7 (continued). Bus waits at foot of hill for walkers. Outcrops on hill are of rhyodacite welded tuff and a few intercalated thin beds of quartzitic sandstone of the middle member of the formation of Mt. Wrightson (Triassic). Highest ridge to south is an extension of this unit; ridge to south-southeast is capped by andesitic and rhyolite volcanics, thick eolian sandstone, and some pillow lavas, all of the upper member of that formation; spur to west-southwest is underlain by a leucocratic quartz monzonite of Laramide age; and the saddle west of the spur is underlain by a Laramide granodiorite.

intrusive!

.4	30.8	Junction. Keep on main road to right (NW).
1.3	32.1	Junction. CAUTION. Turn right (NE) through cattle guard and then immediately to the left (N) onto Helvetia road.
.6	32.7	Junction. Keep straight ahead (NE) on main road.
.5	33.2	Crossroad. Keep straight ahead (NE).
1.1	34.3	Junction. Keep straight (NE) ahead on main road.
0.4	34.7	Junction. Turn right (NE) on main road crossing Box Canyon wash.
1.7	36.4	Junctions. Keep straight ahead (NE) on main road.
.6	37.0	Precambrian Granodiorite east of road contains abundant pods and dikes of aplite. Huerfano Butte and pediment to northwest are underlain by Laramide quartz monzonite. At the butte there also is altered aplite.

1.5	38.5	Junction. Keep straight ahead (E) on Sahuarita-Helvetia road.
.1	38.6	Junction. Turn left (NE) on main road, to Helvetia.
.3	38.9	Cemetery on left (NW) side of road.
.9	39.8	STOP 8. Park at junction. Review geology of west side of Helvetia district. Peach Hill to northeast is underlain, in rising succession, by Precambrian granodiorite, a brown rib of tectonically thinned Cambrian Bolsa Quartzite, slivers of metamorphosed Cambrian Abrigo Formation and Devonian Martin Formation, and a cap of Pennsylvanian Horquilla Limestone. A major thrust fault underlies the quartzite and minor ones overlie it and overlie the Martin. East of Peach Hill the rocks above this major thrust fault also include Permian and Cretaceous rocks. Together they are here called rocks of the Helvetia klippe.

The Helvetia klippe is 1 1/2 miles long and 3/4 mile wide; its well-exposed basal thrust fault dips inward to form a saucer-shaped surface. Abundant drill holes, as reported by A. M. Heyman and by F. A. Michel in their unpublished MS theses (Univ. of Arizona), provide more detail on the position and configureation of this thrust fault, and show that, where penetrated by drilling, the klippe lies on granitic rock. Present work indicates that the klippe rests on the edges of two stocks of Laramide quartz monzonite (K-Ar 52.2 ± 1.6 m.y.) and probably on a septum of Precambrian granodiorite separating the stocks. The center and eastern end of the klippe is cut by (or contains?) a small quartz latite porphyry stock of late Laramide (m.y.)

Resume trip, keeping to main road (E).

0.5	40.3	Junction. Keep to main road, straight ahead (E) and past the ghost town of Helvetia. Production has been largely of Cu, Pb, and Ag, valued at about $4 million between 1908 and 1950.

.2	40.5	Junction. Keep to main road, straight ahead (E).
.2	40.7	STOP 9. Roadcut exposes thrust fault at the base of the Helvetia klippe, here consisting of the Permian Scherrer Formation. The klippe overlies Laramide quartz monzonite (K-Ar 52 m.y.) that underlies the entire basin to the south. Therefore the fault is part of Phase 3 of Laramide deformation. Hill to east is capped by the Permian Concha Limestone, a slice of which the road crosses just to the north. Farther along the road to the northeast the Concha is separated from altered rocks of the Bisbee by a northwest-trending vertical fault zone, along which there has been considerable mineralization.

0.4 41.1 STOP 10. Walk up road on hill to the southwest for a review of the geology of the east side of Helvetia district. Range crest to the southeast is underlain by the Precambrian granodiorite, capped by steeply eastward-dipping Bolsa Quartzite. The hill on the range crest to the east, between the roads, is underlain by a small stock of quartz latite porphyry that is suggested by Michel and Heyman to be the root area of the quartz latite porphyry body involved in the Helvetia klippe. The ridge north of this hill is capped by Permian Concha Limestone and Rainvalley Formation. The low hills half a mile to the northeast of STOP 10 contain imbricate thrust slices of lower Paleozoic rocks and of Precambrian granodiorite. These thrust plates truncate several northwest-trending tear faults, a pattern repeated at other places in the district (see fig. 1). Note on the map that other tear faults merge with thrust faults, to show their contemporaneity. Several of the quartz monzonite stocks cut thrust faults and locally are injected along tear faults, thereby concealing portions of the tear. These stocks, then, serve to separate phase 2 from phase 3 of

the Laramide orogeny; the one phase of deformation predates the stocks, the other phase of deformation postdates the stocks directly, or postdates the structures that controlled the emplacement of the stocks.

A problem arises here concerning the geologic relations between the quartz latite porphyry stock associated with the Helvetia klippe and the thrust fault beneath the Helvetia klippe. Does the stock cut the thrust fault, or has it been transported in, perhaps from the stock along the range crest to the east? Neither the evidence obtained from a drill hole through the edge of the small outlier of the stock directly north of Helvetia townsite, as cited by Michel and Heyman, nor the relations around the east edge of the stock provide conclusive evidence of the relations. Although the solution of this problem is immaterial to the 3-phase Laramide thesis, it may be important to the explanation of the timing and of the controls of mineral emplacement.

Walking tour of area of tear faults, east edge of Helvetia klippe, and stock follows.

Resume trip, returning past Helvetia townsite and STOP 8.

2.5	43.6	Junction. Keep right (W) on main road toward Sahuarita.
.1	43.7	Junction. Keep right (NW) on main road toward Sahuarita.
.8	44.5	Crossroad. Turn right (NE).

1.4 45.9 STOP 11 (optional). Park at junction immediately past the cattleguard. Bus turns while group walks north along road about 100 yards to see the overturned fold of Mississippian Escabrosa Limestone and Pennsylvanian Horquilla Limestone. Dark-gray conglomeratic phyllite lies at or near the base of the Horquilla where it is as severely metamorphosed as it is here; elsewhere there are two thin clastic beds 50 to 120 feet above the base. Note that the fold axis strikes parallel to the tear faults of phases 2 and 3, to suggest the fold was formed before the northwest-trending tear faults and their associated thrust faults. The early deformation (deformations?) is geologically dated in 3 situations: (1) In several places in the Santa Rita and Empire Mountains undeformed uppermost Cretaceous volcanics lie unconformably on folded Lower Cretaceous rocks; (2) An unconformity in the northern Huachuca Mountains, 30 miles southeast of Helvetia, places Upper Cretaceous rocks across a tear fault which bounds thrust faults in Lower Cretaceous rocks; (3) Some rocks of Upper Cretaceous age in the southern Santa Rita

and Huachuca Mts. are folded in a system parallel to the folds in nearby Lower Cretaceous rocks. Phase 1, then occurred during early Late Cretaceous or slightly later Late Cretaceous time, and it may not be fully synchronous throughout the region.

		Return to Sahuarite-Helvetia road.
1.4	47.3	Crossroad. Turn right (NW) on main road.
10.5	57.8	Follow main road to the fields along the Santa Cruz River Valley. Turn left (W).
.7	58.5	Sahuarita. End of field trip. Turn right (N) on Highway 89 for Tucson.

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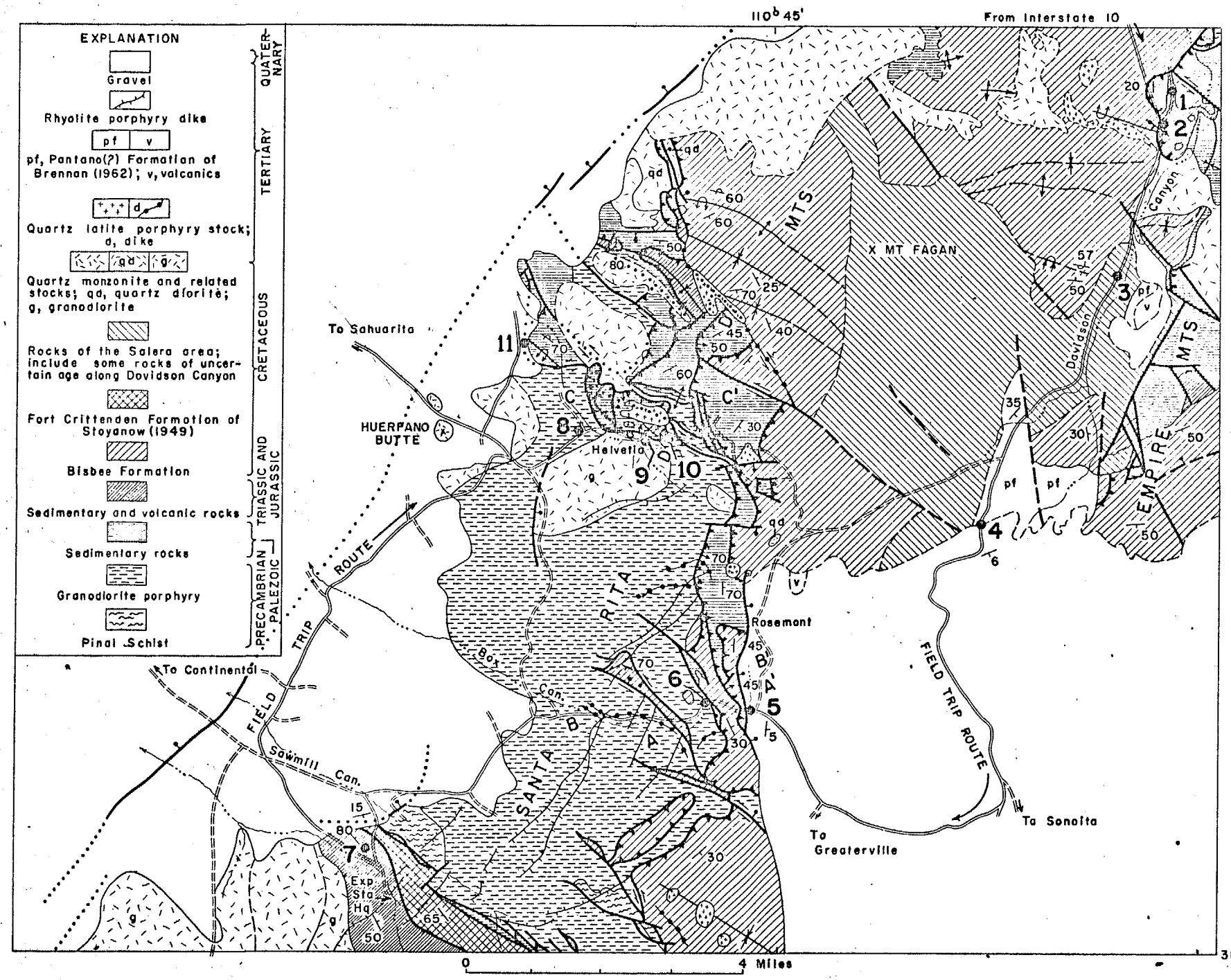
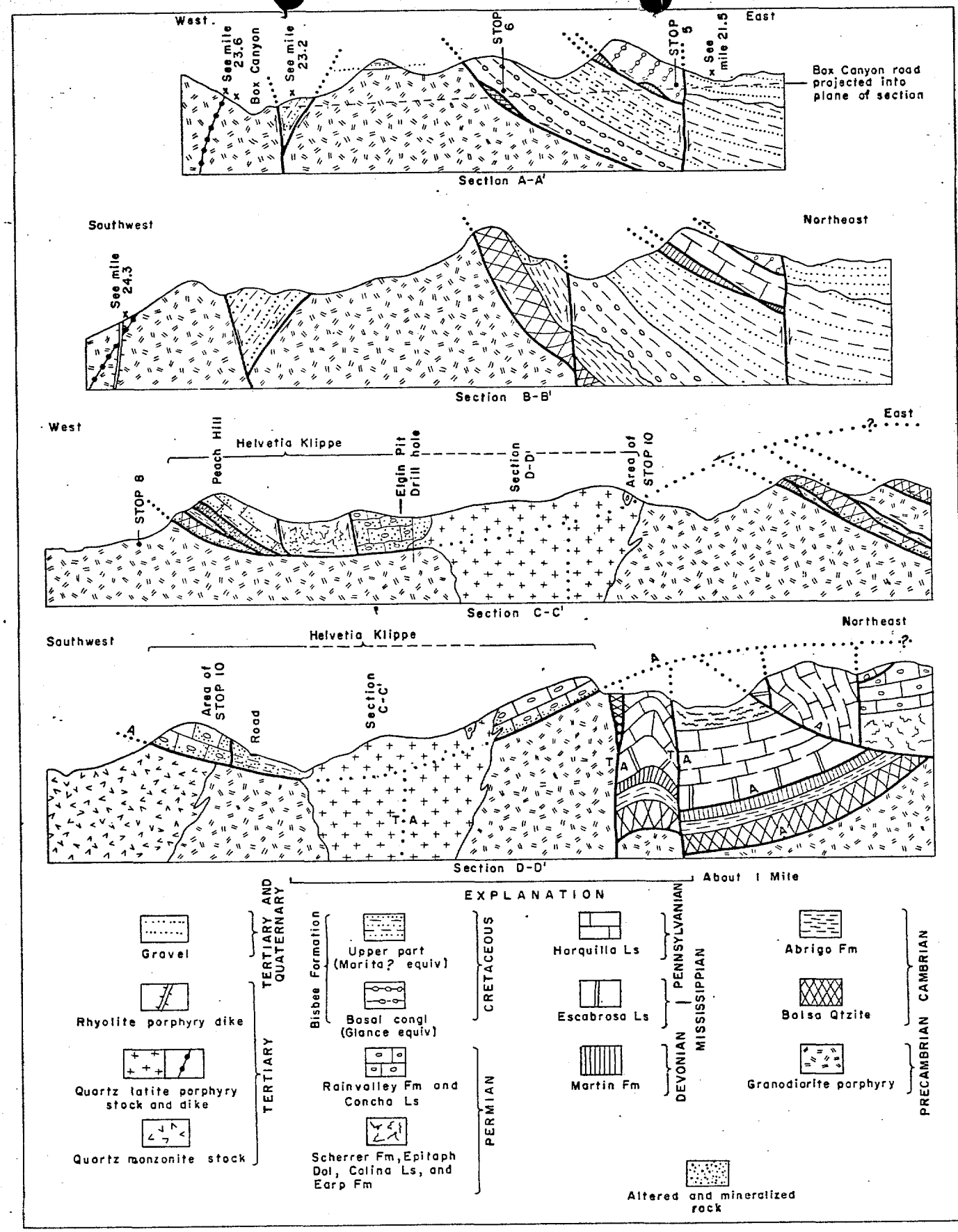

EXPLANATION
Gravel
Rhyolite porphyry dike
pf, Pantano(?) Formation of Brennan (1962); v, volcanics
Quartz latite porphyry stock; d, dike
Quartz monzonite and related stocks; qd, quartz diorite; g, granodiorite
Rocks of the Salero area; include some rocks of uncertain age along Davidson Canyon
Fort Crittenden Formation of Stoyanow (1949)
Bisbee Formation
Sedimentary and volcanic rocks
Sedimentary rocks
Granodiorite porphyry
Pinal Schist
QUATERNARY
TERTIARY
CRETACEOUS
TRIASSIC AND JURASSIC
PRECAMBRIAN PALEZOIC
110° 45'
From Interstate 10
To Sahuarita
HUERFANO BUTTE
Helvetia
X MT FAGAN
SANTA RITA MTS
EMPIRE MTS
Davidson Canyon
Box Can.
Sawmill Can.
Rosemont
To Continental
FIELD TRIP ROUTE
To Greaterville
To Sonoita
Exp Sta Hq
0
4 Miles
31° 45'


West
East
See mile 23.6
Box Canyon
See mile 23.2
STOP 6
STOP 5
See mile 21.5
Box Canyon road projected into plane of section
Section A-A'
Southwest
Northeast
See mile 24.3
Section B-B'
West
East
Peach Hill
Helvetia Klippe
Elgin Pit Drill hole
Section D-D'
Area of STOP 10
STOP 8
Section C-C'
Southwest
Northeast
Helvetia Klippe
Area of STOP 10
Road
Section C-C'
Section D-D'
About 1 Mile
EXPLANATION
Gravel
TERTIARY AND QUATERNARY
Rhyolite porphyry dike
Quartz latite porphyry stock and dike
Quartz monzonite stock
TERTIARY
Bisbee Formation
Upper part (Morita? equiv)
Basal congl (Glance equiv)
CRETACEOUS
Rainvalley Fm and Concha Ls
Scherrer Fm, Epitaph Dol, Colina Ls, and Earp Fm
PERMIAN
Horquilla Ls
PENNSYLVANIAN
Escabrosa Ls
MISSISSIPPIAN
Martin Fm
DEVONIAN
Abrigo Fm
Bolsa Qtzite
CAMBRIAN
Granodiorite porphyry
PRECAMBRIAN
Altered and mineralized rock

J.H.C.

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DEC 7 1967

AMERICAN SMELTING AND REFINING COMPANY
Tucson Arizona

November 16, 1967

MR. WES SHB, GWH

W.E.S.

DEC 7 1967

READ AND RETURN

PREPARE ANSWERS HANDLE

FILE INITIALS

TO: Mr. J. H. Courtright

FROM: J. R. Wojcik

Utah Geological Society Field Trip
Uranium Districts--Southeastern Utah

The Utah Geological Society conducted a 3-day field trip through the uranium districts of Southeastern Utah, beginning September 28, 1967. All transportation was furnished by UGS in the form of two chartered Greyhound buses.

The first day's trip consisted of travel from Salt Lake City to Moab. I joined the trip in Moab.

On the second day the group visited the location of Texas Gulf Sulfur's mine at Potash, Utah, and the uranium districts of Kane Creek, La Sal Creek, Lisbon Valley and Big Indian. Tours were conducted through Continental Materials' Rattlesnake open pit mine and Homestake's North Alice mine.

On the third day, the trip was routed from Moab to Salt Lake City via Monticello, Blanding, Cottonwood Wash, Fry Canyon, White Canyon, Hite, Hanksville and Green River. Short stops were made at the Basinere Copper Leach Mill in Fry Canyon, the Happy Jack Mine, and the Trachyte Ranch uranium occurrence east of the Henry Mtns.

Approximately 80 geologists attended the trip and represented such companies as Kennecott, USSR & MCo., Phelps-Dodge, Amerada Petroleum, Pan Am Petroleum, Conoco, Getty Oil, Texaco, Anaconda, Union Oil, Humble and Pure. People from the uranium companies (Union Carbide, Climax, Rio Tinto, Homestake) were conspicuously absent.

At the first stop at Potash, a brief description of the deposit was presented. Within the Pennsylvanian Paradox formation here on the flank of the Kane Creek anticline, the USGS has identified 29 salt beds numbered from top down, S-1, S-2, etc. The potash beds of importance are at the top of S-5 and S-9. Present production is from the Syl-5 bed at a depth of about 2700'. Syl-5 averages about 12' thick with a maximum of about 20'. Mine geologist Phil Van Alstine told the group that the shaft is 2780' deep and programmed for 10,000 tpd, although the average for September was 4900 tpd. Mining is by room and pillar method. TGS is having a second 6' dia. shaft drilled to 2800' by Camay Drilling Co. This will be a supply shaft as well as an escapeway.

While at Potash, a brief summary was presented of the Kane Creek uranium district. Mineralization occurs in the Permian Rico and Cutler formations and Triassic Mossback formation along a fault where formations have collapsed along

the Kane Creek structure. Uranium-vanadium ratio in the Cutler formation is 4:1 while that along the rest of the Kane Creek structure is about 1:2. Ash from petroleum found along the Kane Creek structure contains a high percent vanadium. Only about 6500 tons of ore have been produced from the Kane Creek District in the past 10 years.

Deposits around the La Sal Mtns. were described at a stop in Spanish Valley south of Moab. Mines in the Upper Salt Wash member of the Morrison formation have produced about one million tons of ore in the past 10 years from Beaver Mesa and Polar Mesa east and northeast of the La Sal Mtns. Here the Upper Salt Wash is up to 100' thick with ore occurring on Polar Mesa along local changes of dip. Ore bodies range up to 5,000 tons each. West of the La Sal Mtns., in Upper Kane Creek, there are two ore horizons in the Salt Wash. Production from Upper Kane Creek during the last 10 years is about 39,000 tons of ore.

At the junction of Utah 46 with the Lisbon Valley-Big Indian road, we saw a large oil well type rotary drill just to the northeast. Later, I learned that this is Arapahoe Drlg. Company drilling 2800' holes to the basal Chinle for Conoco. This is Conoco's fifth well in a series along the trend of the extension of the North Alice orebody which extension has been offset downward along the Lisbon Valley fault. Dr. Kenneth Smith of Conoco's Denver office told me that the drilling is costing them $4.75/ft. and that they are not coring at all. All drilling is with air and they are using a hammer drill through the Dakota. In the course of their program, they supposedly have found some 20,000 tons of possible ore in the Morrison formation and they intend to lease this to a local small operator.

Further south, Rio Tinto is supposed to have blocked out a sizeable tonnage directly across the Lisbon Valley fault from the North Alice. Whatever the case, they have drilled upwards of 70 holes to depths of about 2800'. They have a Car Mac Drlg. Company rig operating now in that area.

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A stop at the Rattlesnake Mine showed this to be rather typical of the ore bodies in the Salt Wash. The Rattlesnake is very close to the Lisbon Valley fault and, in fact, is traversed by one strand of the fault. To date, the Rattlesnake's 100,000+ ton ore body is the largest reported east of the Lisbon Valley fault. The Lisbon Valley fault is just east of the crest of the Lisbon Valley Anticline which is a salt anticline similar to the Kane Creek and the Gypsum Valley.

Before our trip underground at the North Alice Mine we saw plan maps which showed the trend of the ore body as slightly north of the strike of the Lisbon Valley fault and consequently terminates against the fault. The ore at the North Alice is at the base of the Chinle to about 20' above the Cutler. Thickness of ore ranges up to 12' but averages about 3'. Bedded red chert is common in the ore zone and much of the uraninite and coffinite are finely distributed in a hard red matrix. Production at present is about 250 tpd at 0.42% U308 although the material being hoisted up the incline when I visited was running between 0.55% and 0.75%.

A brief visit to the Micro Copper Corporation's mine showed copper minerals (oxide and sulfide) in a sandstone member of the Dakota. Reportedly, ore bodies can run to 1000' x 100' laterally by 10' thick @ 1% or better copper. Micro Copper concentrates the ore by a "unique dry process" to a copper powder. They claim present production to be over 4,000 lbs. of powder per day but the operation was inactive at the time of our visit.

All stops on September 30 are well explained in the Guidebook #21 "Second day road log" and no additional significant information was disclosed. Most of the discussions were led by H. H. Doelling and Howard Ritzma of the Utah Geological and Mineralogical Survey and R. E. Cohenour of the A.E.C. with additional comments by Dr. Stokes. The entire trip was very well organized and a credit to the Utah Geological Society, notably Roland Mulcahy and Allen James, who were presiding officers this year.

J. R. Wojcik (lmi)

JRW:lmi J. R. Wojcik

Attachments: Guidebooks Nos. 9 & 21

FIELDNOTES
From The Arizona Bureau Of Geology And Mineral Technology

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HELIUM: Origin, Use, Supply and Demand

by Jon E. Spencer

INTRODUCTION

Most people give little thought to helium gas except when it is used to inflate children's balloons at circuses or parades, or when its properties are revealed in a high school chemistry class. Helium is actually a unique and indispensable natural resource that is crucial for many industrial and research activites. The following narrative describes the geologic occurrence and physical properties of helium, outlines the history of its discovery and development as a natural resource, and examines possible future uses of helium as well as the consequences of its depletion.

Several natural gas fields in the United States contain most of the world's known helium reserves. Most natural gas contains small amounts of helium which, unless extracted from the natural gas, are lost to the atmosphere when the gas is burned. Roughly 14 billion cubic feet of helium (about one-tenth of a cubic mile) are contained in natural gas produced domestically each year. About one billion cubic feet of this helium is extracted and sold commercially, while the rest is dissipated into the atmosphere. The atmosphere is a virtually limitless and renewable source of helium, but the cost of atmospheric recovery of helium is high due to the increased energy requirement for extraction from such a dilute source (five parts helium per million parts air). It is estimated that it would cost $2,000-$6,000 to extract a thousand cubic feet of helium from the atmosphere, compared to less than $13 for extraction of the same quantity from natural gas containing more than 0.3 percent helium (3,000 parts per million) (Peach, 1981).

The importance of helium to industry and scientific research, and its possible importance to future energy-related industries, has long been recognized. As a result, efforts have been made to extract helium from natural gas and to pump it underground into depleted natural gas reservoirs where it can be stored indefinitely. About 40 billion cubic feet of helium have been stored in the Cliffside reservoir in northern Texas by the U.S. Bureau of Mines before federal funding for helium extraction and storage was terminated in 1973 for budgetary reasons. Despite legislative attempts to revive the helium conservation program, it is not likely to be renewed in the near future. At current rates of helium production and discovery, the world's underground helium reserves will be depleted by the middle of the 21st century. However, as helium-intensive energy technologies become practical and helium reserves are depleted, the debate over the merits of federally funded helium conservation will intensify. Advanced electric power generation, storage, and

The Goodyear "blimp"—one of four lighter-than-air craft in the Goodyear fleet today. Since 1917 Goodyear has built more than 300 helium-filled dirigibles; 60 of these have been used as commercial airships which also promote community activities and public service throughout the U.S. and Europe. A "blimp" is 192 feet long, 59 feet high and weighs 9,500 pounds when empty; it travels 35-50 mph at heights of 1,000-10,000 feet, and can carry a maximum load of 2,820 pounds. Photo courtesy of Goodyear Aerospace Corporation.

transmission devices, now in research and development, may require large amounts of helium in the future.

ORIGIN OF HELIUM

Helium is the second element on the periodic table of the chemical elements and is the second most abundant element in the universe. Only hydrogen, the first element on the periodic table, is more abundant. The sun's energy is derived almost entirely from fusion of hydrogen nuclei into helium nuclei. In fact, the sun and stars can be regarded as enormous helium factories.

On Earth where temperatures and pressures are far too low for nuclear fusion, much smaller amounts of helium are produced by radioactive decay of uranium and thorium. A single atom of uranium 238, the most abundant isotope of uranium, produces eight helium nuclei during its long decay into lead. Over millions of years, trillions of cubic feet of helium have been produced by radioactive decay of uranium and thorium in the Earth's crust. Helium produced in the Earth is initially trapped in the rocks and minerals in which it is formed. Large amounts of helium eventually escape into the atmosphere, and from there escape into outer space. Smaller amounts, however, accumulate in underground geologic reservoirs. Both natural gas and helium accumulate in porous and permeable sedimentary rocks overlain by impermeable strata, although the two types of gas are derived from different sources. Helium is derived from rocks rich in uranium, whereas natural gas is derived from rocks rich in organic matter. The two types of gas are typically found together in underground reservoirs, although the relative concentration of each varies greatly because of differences in the concentrations of uranium and organic matter in source rocks.

DISCOVERY AND EARLY USES OF HELIUM

Helium was discovered simultaneously by British astronomer Norman Lockyer and French astronomer Pierre Janssen in 1868. Lockyer noticed that a bright yellow spectral line which appeared in light emitted from the sun's corona was an element not known on Earth. He later named the element "helium", from the Greek word for sun, *helios* (Seibel, 1968).

Twenty-three years later (1895) in a London laboratory, professor William Ramsay dissolved one gram of the uranium-bearing mineral cleveite in acid and obtained a gas which he purified and examined spectroscopically. Because he did not recognize the gas, Ramsay sent a sample to Sir William Crooke, a noted spectroscopist, who identified it as helium. Within a few years of this discovery, helium had been found in a variety of uranium and thorium-bearing minerals, and in the air.

In 1905 Dr. H.P. Cady of the University of Kansas analyzed gas from a natural gas well in Dexter, Kansas, and discovered that it contained almost two percent helium. Afterward, Cady and his colleague, Dr. D.F. McFarland, analyzed 44 samples from natural gas wells in Kansas, and recognized the widespread occurrence of helium in natural gas. Cady spoke wisely when he stated: " . . . helium is no longer a rare element, but a very common element, existing in goodly quantity for the uses that are as yet to be found for it" (Seibel, 1968).

Techniques for large-scale extraction of helium from natural gas were developed for military purposes. The Germans made much use of hydrogen-filled zeppelins during World War I. These lighter-than-air vehicles could drop bombs from 16,000 feet, which was higher than airplanes of the time could fly. Using rockets that exploded in a shower of sparks, the British learned that a single spark could send a zeppelin crashing to the ground as flaming wreckage. The advantages of using nonflammable helium became obvious, and, by 1917, the U.S. Bureau of Mines was financing research and development of helium-extraction plants. The first significant quantities of helium were not available until the end of World War I. However, research and development continued, and large quantities of helium were available for use as a lifting gas in airships during World War II. Many new uses for helium, some of them related to national defense, were found during the years immediately following the second world war.

HELIUM CONSERVATION

In a 1954 report prepared for the U.S. Bureau of Mines, the need for helium conservation was addressed:

> Since the helium occurs in mixture with the natural gas . . . present reserves of helium are being dissipated every day as a part of the large natural gas deliveries to the fuels markets. . . . The alternatives to permitting the rapid disappearance of the helium reserves is to institute an active program for conservation of a large quantity of helium as a national asset for the more distant future [Henrie and others, 1978].

Following this and later studies of helium supply and demand, the federal government passed the Helium Act Amendments of 1960. This act authorized the Bureau of Mines to enter into contracts for the purchase of helium during the following 25 years.

Shortly after the passage of the Helium Act Amendments, several companies constructed helium extraction plants and began selling helium to the U.S. Bureau of Mines under contract agreements. The Bureau pumped the helium into the Bush Dome at its Cliffside-field subsurface geologic storage reservoir near Amarillo, Texas. The helium was injected into the center of the domal-shaped reservoir rock, while natural gas was pumped from the margins. When helium purchases were terminated in 1973, 36 billion cubic feet of helium had been extracted and stored at a cost of more than $300 million.

HELIUM PROPERTIES AND USES

Helium has a number of unique properties that make it useful in a variety of applications. Originally used only as a lighter-than-air lifting gas, it now has over 75 uses, most of which were developed after World War II. Three major uses—cryogenics, heliarc welding, and purging and pressurizing—account for about two-thirds of domestic helium uses (Figure 1; Table 1).

The following description of helium uses is based on reports by Davis (1980), Henrie and others (1978), and Midwest Research Institute (1977):

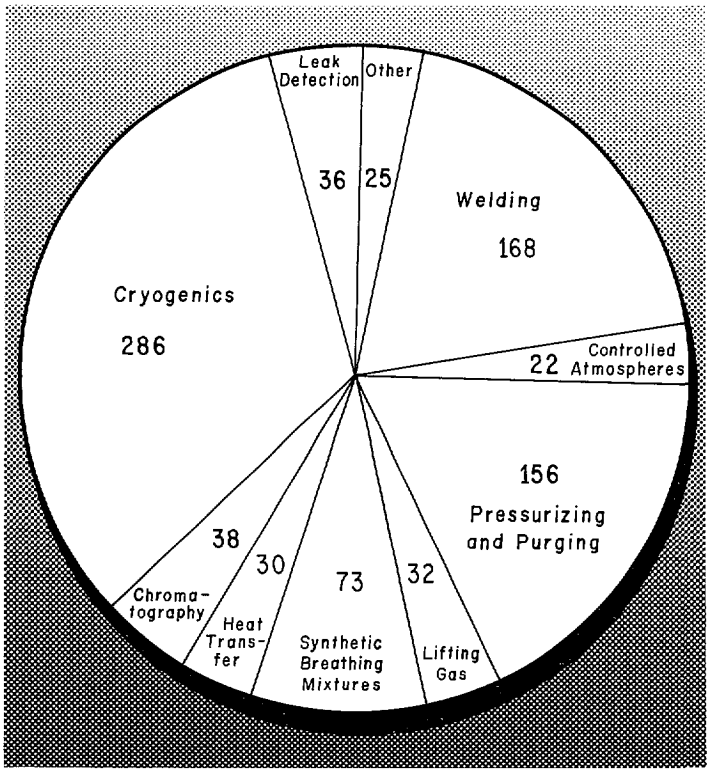

Figure 1. Uses of helium in the United States in 1981, based on U.S. Bureau of Mines data (Tully, 1982). Total helium used in the U.S. was about 866 million cubic feet.

Cryogenics

Cryogenics refers to scientific and engineering work performed at temperatures below about -232° F (-153° C) and above absolute zero, -459° F (-273° C). [It is theoretically impossible to reach absolute zero, although scientists have come extremely close]. Helium is the only known substance that remains liquid at extremely low temperatures and can be used as a coolant to achieve and maintain temperatures within 14° C (25° F) of absolute zero. [Hydrogen, the closest competitor of helium, freezes at -259° C (-434° F)].

At temperatures within a few degrees of absolute zero, some substances become superconductive, a condition in which the resistance to the flow of electricity is zero. Achieving superconducting temperatures is one of the most important uses of helium, although some materials become superconductive above the freezing temperature of hydrogen. Superconducting electromagnets, for example, produce intense magnetic fields at about one-tenth the operating cost of conventional electromagnets. A major use of superconducting magnets at present is in particle physics research. Research is being done to develop superconducting magnets for magnetic-confinement fusion power generation, MDH (magnetohydrodynamic) power generation and magnetic electricity-storage devices. Superconducting generators and motors are also being studied. Widespread commercial use of these technologies is unlikely for at least the next 20-30 years.

Superconductivity is also important for a number of electronic instruments, including masers (microwave equivalent of lasers) for microwave communications with satellites, highly sensitive infrared detectors for military observation satellites and astrophysical research, and NMR (nuclear-magnetic resonance) imaging, a technique that may replace X-rays in medical applications. Research on superconducting computer elements, and a whole variety of scientific instruments based on superconductivity, could lead to dozens of new uses for helium as a refrigerant.

Welding

Many metals, such as aluminum, magnesium, and stainless steel, cannot be welded together by arc welding under normal atmospheric conditions because the molten metal reacts with oxygen and nitrogen in the atmosphere. These metals can be welded, however, by use of inert-gas-shielded arc welding. In this technique, the electrical arc providing heat to the metal is surrounded by a jet of inert gas that shields the arc and the metal from reactive gases in the atmosphere. Helium is preferred over argon in most situations because it improves weld penetration and appearance, and allows greater welding speed.

Pressurizing and Purging

Helium has a number of properties, including chemical inertness, very low boiling point, low solubility, and low density, that make it ideal for pressurizing and purging such things as rocket fuel tanks. NASA has been the primary

	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
WORLD PRODUCTION											
United States	760	647	577	627	647	699	745	808	947	1,001	1,062
Rest of World	90	90	112	122	132	140	146	146	149	149	181
Total World Production*	850	737	689	749	779	839	891	954	1,096	1,150	1,243
U.S. DEMAND PATTERN											
Purging and pressurizing	271	219	164	180	149	116	109	114	140	146	147
Controlled atmospheres	78	63	46	52	53	63	16	19	21	21	21
Welding	72	58	52	57	91	106	97	102	151	157	158
Lifting gas	51	41	23	25	11	11	23	25	29	30	30
Leak detection	48	38	32	36	30	37	25	25	32	34	34
Cryogenics	112	90	104	113	123	127	207	223	258	268	270
Chromatography	16	13	19	21	21	21	25	25	33	35	36
Heat transfer	10	8	9	10	16	37	24	25	27	28	28
Breathing mixtures	5	5	14	16	27	32	55	57	65	68	69
Other uses	7	7	7	5	9	20	20	19	23	24	24
Total U.S. Demand*	670	542	470	515	530	570	601	634	779	811	817

*Estimated Amounts

Table 1. U.S. and world production of helium, and U.S. demand pattern, 1969-1979 (Davis, 1980).

consumer of helium for this purpose. Helium is the only gas that can be used to pressurize liquid hydrogen in rocket fuel tanks because all other gases freeze at liquid hydrogen temperatures.

Breathing Mixtures

Compared to other gases, helium is relatively insoluble in liquids and, therefore, relatively insoluble in human blood. Deep-sea divers, using helium-oxygen breathing mixtures at depths greater than 100-200 feet, can return to the surface much more rapidly than divers using conventional nitrogen-oxygen breathing mixtures. Because nitrogen is more soluble in blood than helium, it will form bubbles upon rapid decompression, a potentially fatal condition known as the "bends." Helium is widely used for breathing mixtures by companies involved in offshore oil and gas exploration and production, and by U.S. Navy divers.

Chromatography

Gas chromatography is an analytic process by which volatile substances can be separated into individual components by flowing the sample and a carrier gas through an adsorbant medium. Helium is preferred as a carrier gas in most cases because of its high thermal conductivity, low solubility, and chemical inertness. About 80 percent of the 40,000 chromatographs in operation today employ helium as a carrier gas.

Leak Detection

Helium is used to detect and locate minute leaks in pressure and vacuum systems because it has the highest diffusion coefficient of any gas (i.e., the ability to go through microscopic holes and to diffuse throughout a medium), and it can be easily detected. Helium detectors are now sufficiently sensitive to detect a leak with a flow rate such that one tablespoon of helium would take 100,000 years to pass through an opening. Leak detection capability has been of great value to the semiconductor, nuclear, aerospace, refrigeration, and food canning industries, as well as to many scientific laboratories.

Lifting Gas

The dangers of using hydrogen as a lifting gas are exemplified by the explosive fire that destroyed the hydrogen-filled dirigible "Hindenberg" in 1937. Helium has 93 percent of the lifting power of hydrogen, but no explosive potential. Primary uses of helium as a lifting gas include weather balloons, upper-atmosphere research balloons, blimps used for advertising (see cover photo), and balloons used to transport logs from inaccessible logging areas to collection points.

Heat Transfer

Helium is an ideal heat transfer medium because it has a high thermal conductivity and high heat capacity, and is chemically inert. Helium is used as the primary coolant in some gas-cooled nuclear reactors. In addition to the properties mentioned above, the high resistance of helium to neutron bombardment makes it ideally suited for this application. Several high-temperature, gas-cooled nuclear reactors (HTGRs) in this country and Europe have demonstrated the benefits of this design over conventional water or steam-cooled reactors. The Fort St. Vrain Nuclear Generating Station, a 330 megawatt HTGR in Colorado, is this country's only large helium-cooled reactor. Unlike conventional water-cooled reactors, helium-cooled HTGRs use large, massive graphite cores to contain the nuclear fuel. In the event of a total coolant loss, serious damage and potential meltdown of the core of a water-cooled reactor begins to occur within 1-2 minutes, whereas at least 10 hours is required to reach critical temperatures in a helium-cooled HTGR. This feature of HTGRs, plus their greater energy efficiency and reduced nuclear waste generation, should make them attractive to public utilities if and when the utilities resume ordering nuclear power plants (Agnew, 1981).

Controlled Atmospheres

A helium atmosphere is used as an inert environment for the growth of high-purity crystals needed by a variety of industries. Germanium and silicon crystals grown in helium atmospheres are used in transistors and other semiconductors, and other crystals with special optical properties are grown for use in lasers and masers. Helium is also used for the purification of rare metals, such as titanium, and in super-high-speed wind tunnels.

Other Uses

There are numerous other small-volume uses of helium which include medical applications, where helium is used as a carrier gas for potentially explosive anesthetics, and for diagnosis and treatment of respiratory disorders. Other miscellaneous uses include lasers, gas-lubricated bearings and high-speed gyroscopes, particle physics research, and improved light sources.

FUTURE SUPPLY AND DEMAND

With the exception of helium stored in the Cliffside reservoir, almost all of the world's economic helium reserves are mixed with natural gas, and most of these helium-rich natural gas fields are in four states (Texas, Oklahoma, Kansas, and Wyoming). Gas from these fields contains about one-half percent helium, while most other gas fields around the world contain helium in considerably lower concentrations. "Economic", or helium-rich natural gas, is generally considered to be gas with more than 0.3 percent helium. Helium can be recovered from natural gas with less than 0.3 percent helium, but the energy requirements, and therefore the costs, are greater.

Because the demand for helium is small relative to the amount of helium pumped from the ground, helium is not generally extracted from helium-rich natural gas, and is lost to the atmosphere when the gas is burned. As long as excess helium is being pumped from underground natural gas fields, there will be no shortage of helium. When demand can no longer be met by extracting helium from natural gas in pipelines, helium will be available from the Bureau of Mines' helium reservoir. At present rates of helium consumption (about one billion cubic feet per year), helium in the federal storage reservoir could supply helium needs for 35-40 years.

Estimating the present volume of total helium reserves and the rate of helium depletion is subject to many uncertainties. Volumes of known natural gas and helium reserves are only approximately known, and estimates of

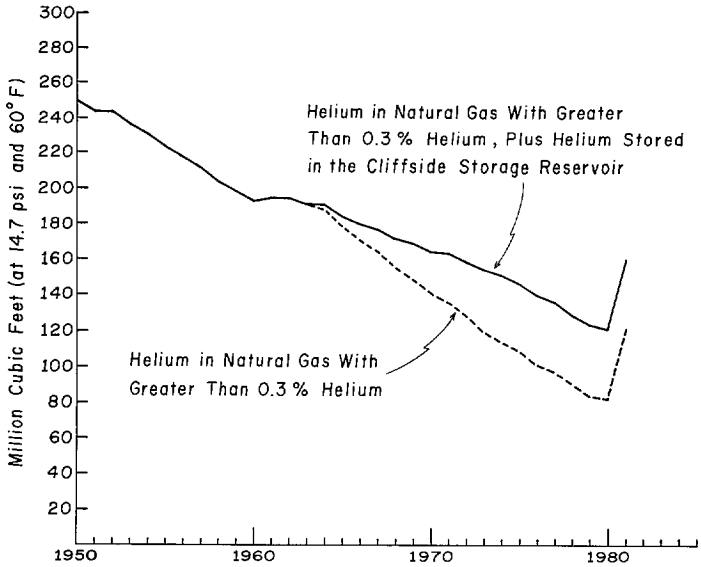

Figure 2. Measured helium reserves in helium-rich natural gas (>0.3 percent helium), in the United States and in the Cliffside storage reservoir (Hertweck and Miller, 1983). Note that new discoveries have not kept up with depletion of producing gas fields. The large increase in helium reserves in 1981 is due to increased estimates of the amount of helium in the Tip Top field of southwestern Wyoming.

the size and helium content of undiscovered natural gas fields are highly speculative. The U.S. Bureau of Mines reported that U.S. helium reserves, as of January 1, 1979, totaled 743 billion cubic feet. This amount includes 141 billion cubic feet of "measured" (proved) and "indicated" (probable) reserves, 40 billion cubic feet in the Cliffside reservoir, and 562 billion cubic feet of "hypothetical" (possible) and "speculative" reserves (Davis, 1980). It is predicted that the *helium-rich* natural gas reserves in the U.S. will be depleted within about 30 years, based on rates of discovery and depletion of proven helium-rich natural gas fields (Figure 2; Cook, 1979). *Helium-lean* natural gas will become an economic source of helium at this time, although the cost of recovery will be substantially larger. By the year 2030, the world's natural gas reserves might be nearing exhaustion. At this point, the only remaining sources of helium will be stored helium, and the atmosphere.

Estimating the future demand for helium is also subject to considerable uncertainty. Millions of dollars are spent each year on research and development of helium-intensive energy technologies that, if developed on a large scale, could involve the consumption of large amounts of helium in the early part of the next century. It is ironic that there may be little helium left if and when new helium-intensive, energy-producing technologies become feasible, and conventional energy sources such as natural gas near depletion.

CONCLUSION

The question of helium conservation is well-stated by Cook (1979): "How [do we] decide whether it is worthwhile to pay a present tangible and calculable cost to conserve a finite resource for uncertain and partly intangible benefits that will accrue mainly to future generations?" Efforts during the past decade to revive the helium conservation program have been unsuccessful. Given current economic problems, it is unlikely that the program will be revived in the near future.

Fortunately, a substantial amount of helium can be conserved without the large expenditure of tax dollars that would be required to revive the helium extraction plants which supply the federal storage reservoir. The Tip Top natural gas field in Wyoming is estimated to contain at least 54 billion cubic feet of helium at a concentration of 0.8 percent (Clark, 1981). Mobil Oil Corporation may soon begin producing natural gas from this field, which will result in loss of its helium reserves. Ninety-five percent of these reserves lie under federal land, and thus, the federal government could require extraction and storage of helium from this gas field, or it could prohibit production until the helium is needed.

As long as our technological civilization exists, helium is likely to be a useful and, in some cases, essential resource. If energy becomes cheap and plentiful in the future, helium can always be extracted from the atmosphere. Should energy become more expensive, as it may if fossil fuels are depleted and other energy sources prove to be costly, helium will be prohibitively expensive for all but the most crucial uses. Given the many unique and outstanding properties of helium, it might be a wise and practical investment in our future to conserve this valuable resource while it is relatively inexpensive to do so.

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LOCAL EVENTS

On October 21, 1983, there will be a symposium on Land Subsidence in Phoenix. Contact Lewis Scott, Arizona Consulting Engineers Association, Suite 111, 3625 N. 16th St., Phoenix, AZ 85016; 602/968-8778.

The 30th Annual Tucson Gem and Mineral Show will be held during February 9-12, 1984 at the Tucson Community Center. For further information, contact the Tucson Gem and Mineral Committee, PO Box 42543, Tucson, AZ 85733.

HELIUM RESOURCES AND PRODUCTION IN ARIZONA

by Jon E. Spencer

INTRODUCTION

Gas fields in Arizona yielded the world's *richest* known helium gas between 1960 and 1977. This helium-rich gas, occurring in the Pinta Dome, Navajo Springs, and East Navajo Springs gas fields near Holbrook in northeastern Arizona, contained about 8-10 percent helium mixed mostly with nitrogen. These gas fields are also somewhat unique because the helium is not mixed with hydrocarbons. The world's *largest* known helium reserves are natural gas fields containing less than one percent helium, and are located in Texas, Oklahoma, Kansas, and Wyoming. These enormous fields contain much greater volumes of helium than Arizona's gas fields, but the helium is more expensive to extract because of its lower concentration.

All known helium occurrences in the state are within the Colorado Plateau and adjacent to the Defiance uplift (Figure 1). Arizona's only *major* helium source is at the south end of the Defiance uplift. The helium reservoir rock is primarily the Permian Coconino Sandstone, although helium has also been reported from red sandstones near the base of the Chinle Formation, and from the upper part of the Pennsylvanian (?)-Permian Supai Formation (Dunlap, 1969; Peirce and others, 1970). A single well in Devonian and Mississippian strata at the north end of the Defiance uplift (Teec Nos Pos oil and gas field, Figure 1) has produced helium, and at present, natural gas containing several percent helium is being vented from a well in the Black Rock field near Teec Nos Pos.

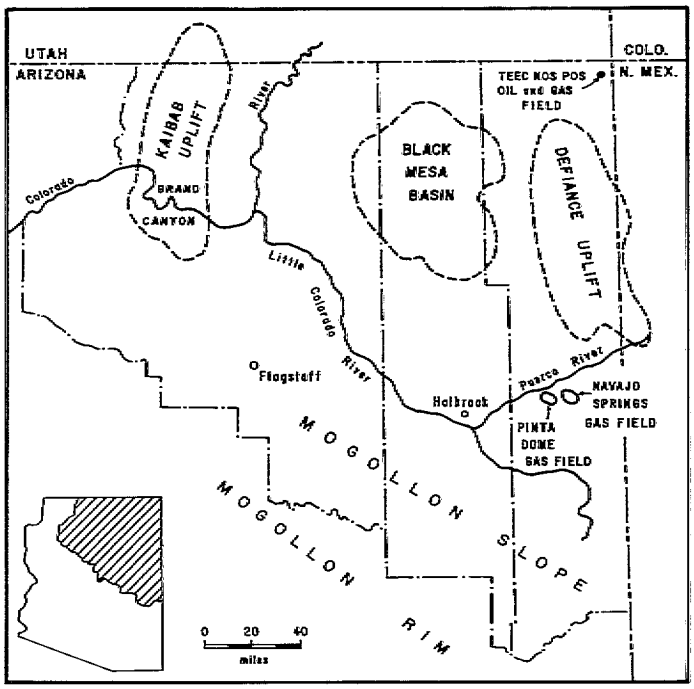

Figure 1. Index map of northeastern Arizona showing location of major geologic features (Dunlap, 1969).

GEOLOGY OF THE PINTA DOME, NAVAJO SPRINGS, AND EAST NAVAJO SPRINGS HELIUM FIELDS

The geology of the Pinta Dome, Navajo Springs, and East Navajo Springs helium fields is characterized by "layer cake" Colorado Plateau stratigraphy, with gentle warps of various sizes that locally produce structural traps for gas accumulation. Each helium field occurs within one of three domal structures separated by faults and closed structural contours. The helium and associated gases occur primarily in the porous Coconino Sandstone which is capped by impermeable shales of the lower part of the Moenkopi Formation. The following description of subsurface geology is based primarily on Dunlap's (1969) study of the area.

Stratigraphy

Lower Paleozoic strata are generally missing in and around the Defiance uplift; consequently, the Pennsylvanian (?)-Permian Supai Formation rests directly on Precambrian granitic crystalline rocks at a depth of approximately 3,000 feet (Figure 2).

The Supai Formation can be subdivided into three members: 1) a basal member composed of approximately 700 feet of siltstone and mudstone; 2) the middle Fort Apache Member, composed of 20-25 feet of dolomitic limestone; and 3) an upper member composed of about 1,000 feet of halite, gypsum, and anhydrite interbedded with shaley siltstone and mudstone. The upper evaporitic member represents the northeast margin of the Holbrook basin.

The Lower Permian Coconino Sandstone is 250-325 feet thick in the helium-producing area and is composed of fine-to-medium-grained, porous and permeable quartz sandstone. Porosity is variable and may be as high as 20 percent. This rock is a productive aquifer, as well as the primary helium reservoir rock in the Holbrook area. The gas-bearing zone is in the upper part of the Coconino Sandstone, whereas middle and lower zones are generally water bearing.

Lower Triassic Moenkopi Formation rests disconformably on Coconino Sandstone, with normally intervening Kaibab Formation completely missing in the Holbrook area. The Moenkopi Formation is composed of variably calcareous siltstone, mudstone, and silty sandstone. Micaceous siltstone and silty mudstone at the base of the Moenkopi Formation form an impermeable cap, preventing upward escape of gas from the underlying Coconino Sandstone.

The Upper Triassic Chinle Formation unconformably overlies the Moenkopi Formation. The basal Shinarump Member consists of 10-60 feet of conglomeratic sandstone and is locally a helium-bearing zone. It is overlain by the lower red member (Akers and others, 1958), which is composed of about 50 feet of sandstone, sandy siltstone, and mudstone, and is also locally helium bearing. The overlying Petrified Forest Member is a sequence of mudstone, siltstone, claystone, sandstone, gypsum, and limestone. Only the basal 200 feet of this member is preserved in the helium-producing area.

The late Tertiary Bidahochi Formation, consisting of 0-180 feet of lacustrine and fluviatile sediments, unconformably overlies the Chinle in some areas around the

SYSTEM OR SERIES		FORMATION	THICKNESS	LITHOLOGIC CHARACTERISTICS
Quaternary				Alluvium, sand and gravel
		UNCONFORMITY		
Tertiary		Bidahochi Formation	0-180	Grayish-brown calcareous sandstone interbedded with silty mudstone and volcanic ash; bentonitic
		UNCONFORMITY		
Triassic	Upper	Chinle Formation	650-850	Reddish-brown to grayish-blue mudstone and claystone with some silty sandstone; some limestone and gypsum in upper portion; siltstone and conglomeratic sandstone in lower portion
		UNCONFORMITY		
	Lower to Middle (?)	Moenkopi Formation	125-150	Brown to gray calcareous siltstone and mudstone; slightly gypsiferous; very silty
		UNCONFORMITY		
Permian	Lower	Coconino Sandstone	250-325	Light gray to buff, fine- to medium-grained sandstone; loosely to firmly cemented with silica
Pennsylvanian (?)		Supai Formation	1,700?	Reddish-brown sandstone, siltstone, and mudstone; some dolomitic limestone; thick interbedded evaporitic sequence in upper portion
		UNCONFORMITY		
Precambrian				Crystalline basement rocks

Figure 2. Generalized stratigraphy of sedimentary rocks exposed at the surface and encountered in the subsurface in the Pinta Dome-Navajo Springs area, Apache County, Arizona (Dunlap, 1969).

helium-producing area. In other areas, this formation has been removed by erosion and Chinle Formation is exposed at the surface. Quaternary sediments locally cover both formations.

Structure

The Pinta Dome, Navajo Springs, and East Navajo Springs helium fields occupy a broad structural saddle between the Defiance uplift to the north, and gently northeast-dipping

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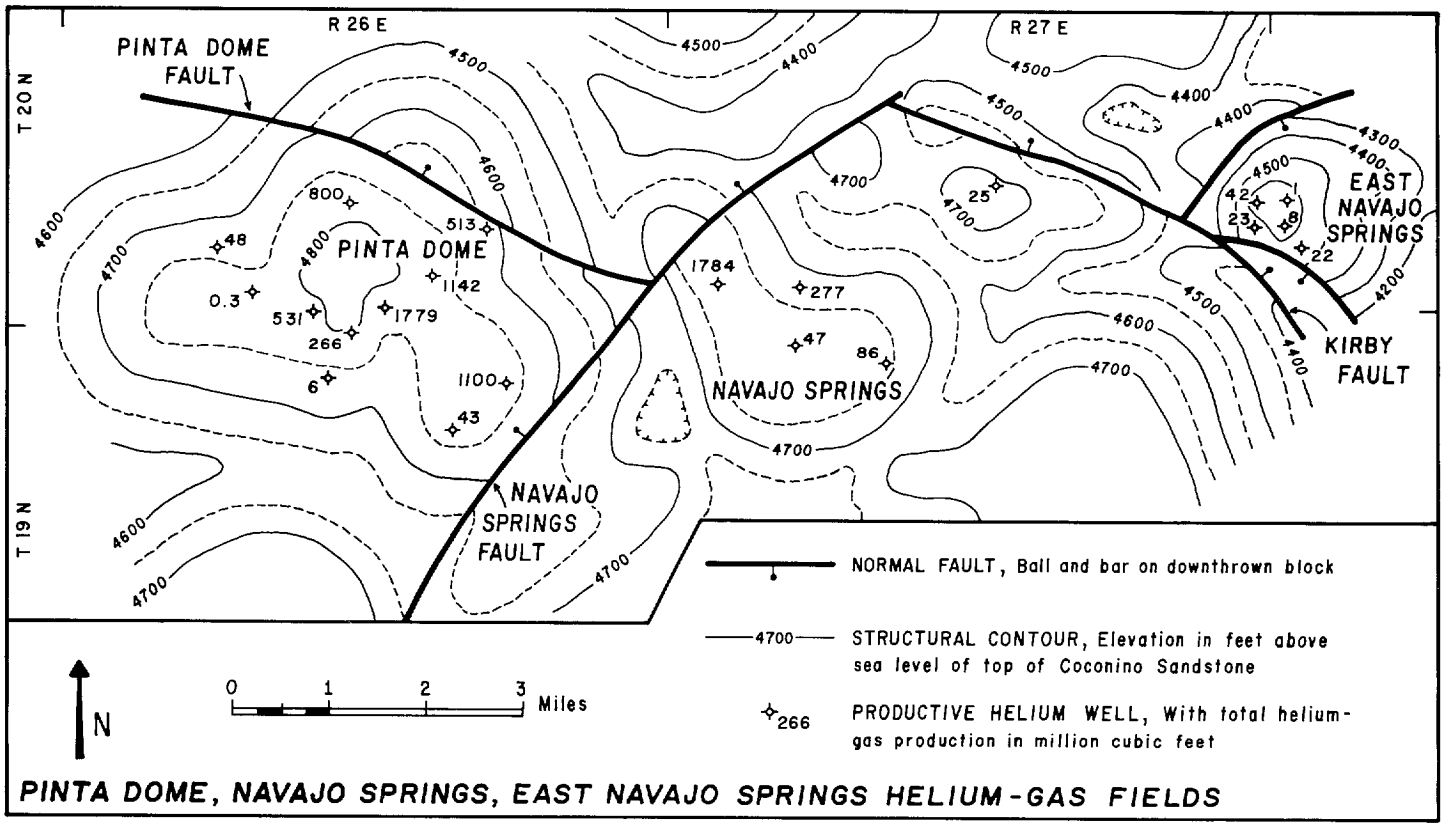

Figure 3. Structure-contour map of the top of the Coconino Sandstone in the subsurface in the Pinta Dome, Navajo Springs, East Navajo Springs area, Apache County, Arizona (Conley and Scurlock, 1976). Also shows location of productive helium-gas wells and amount of helium-gas produced from each gas well in this area (production data from Arizona Oil and Gas Conservation Commission, 1982).

EARTH FISSURES AND LAND SUBSIDEN

by Michael K. Larson and Troy L. Péwé

INTRODUCTION

Earth fissures—long, narrow, eroded tension cracks associated with land subsidence caused by ground-water withdrawal—have formed during the past 50 years in alluvial basins of southern and south-central Arizona (Leonard, 1929; Schumann, 1974; Laney, Raymond, and Winikka, C.W., 1978; Peirce, 1979; Jachens and Holzer, 1982). Until recently, the fissure hazard has been confined to outlying agricultural areas. In January 1980 a 400-foot-long fissure opened in Paradise Valley at a residential construction site of northeast Phoenix. This fissure is the first known occurrence in a densely populated, non-agricultural area of the state, and the first in the city of Phoenix.

Land subsidence and earth fissures pose serious problems for urban areas, with the potential for widespread damage to manmade structures. Well failure is a dramatic manifestation of subsidence as the casing collapses or the well head protrudes above the ground. Canals designed for gravity flow may overflow as a result of local sags and gradient reversals. Water and sewer mains that also depend on gravity flow may reverse flow or clog, and in extreme cases rupture, because of altered gradients. Subsidence may also necessitate new designs of storm drainage systems, and expensive, repeated levelings of benchmarks, resulting in obsolete surveying data. Fissures may directly damage buildings, roads, and other architectural structures. However, even without ground failure, differential subsidence in and of itself may cause damage to structures large in area or height.

Our recently completed study (Péwé and Larson, 1982) outlines in detail the problems of ground-water withdrawal, land subsidence, and earth fissuring in northeast Phoenix (Figure 1). The research consisted of a detailed gravity survey supplemented by geologic mapping, precise, repeated land surveying, and interpretation of well records. The city of Phoenix Engineering Department has provided logistical support, partial funding for the project, and has published the final report.

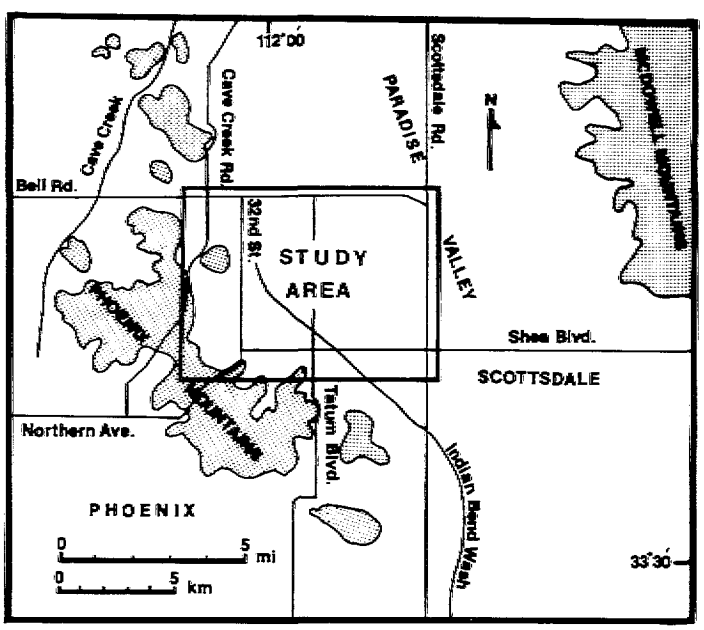

Figure 1. Map of Paradise Valley with study area outlined.

THE PHOENIX FISSURE

The fissure at 40th Street and Lupine Avenue opened 400 feet in an east-west direction, marked by hairline cracks, small open holes, and a linear opening 15 feet long, and as much as 8 feet deep and 15 inches wide (Figure 2). No vertical offset was observed; the fissure appeared to be an example of a tensional break. The crack appeared after locally heavy rains on the weekend of January 19, 1980. Such fissures have been commonly reported after rain showers or application of irrigation water, apparently because the cracks first open below the surface, only to be eroded later by downward percolation of the surface water. At the 40th Street construction site, the overlying soil cover had been scraped off, exposing the subterranean crack, and the collecting of rainwater in a retention basin eroded the large main cavity. The temporary halting of construction, modification of plans, hiring of consultants, and other expenses incurred as a result of the fissure are estimated by the owners of the subdivision to have cost them approximately $500,000.

HISTORY OF GROUNDWATER DEVELOPMENT AND LAND SUBSIDENCE

Water levels remained nearly constant in the study area prior to about 1950, generally within 250 feet of the surface. Increased pumpage in relatively unproductive aquifers has caused rapid water-level decline, particularly in two areas where ground-water has dropped more than 300 feet from its original level. These "cones of depression" are centered halfway between Greenway and Bell Roads at 44th Street and near 56th Street and Thunderbird Road. Withdrawals of ground water are many times the natural recharge rate, and this overdraft has resulted in depletion of thin aquifers peripheral to the mountains, and loss of supply to shallow wells. More wells will certainly become dry as pumping in the area continues.

Since the mid-50s, water levels have declined, resulting in current water depths of more than 500 feet. Subsidence apparently began about a decade later in the vicinity of 52nd Street and Thunderbird Road after water levels declined from 100 feet to 150 feet. Since 1970 the subsidence bowl has increased in size at an average rate of two square miles per year, with early expansion predominantly in a westerly direction, and more recent expansion toward the north and east.

As of March 1982, the maximum subsidence measured was 3.44 feet at 56th Street and Thunderbird Road (Figure 3), near the center of the southern cone of water-level depression. At the assumed center of the subsidence area (or subsidence "bowl") 0.5 miles to the southwest (Figure 3), there is indirect evidence from topographic and land survey data for as much as 5 feet of subsidence. Harmon (1982) noted that the subsidence rate has increased to the south, particularly at 56th Street and Cactus

CE HAZARDS IN NORTHEAST PHOENIX

Figure 2. Earth crack in construction area at Lupine Avenue and 40th Street, Phoenix, Arizona. View is west toward 40th Street. Photo by Troy L. Péwé, No. 4484, January 27, 1980.

Road, and Tatum Boulevard and Cholla Street, where the ground is subsiding 4-5 inches per year. This occurrence may represent a southward shift in the center of the subsidence bowl.

The growth of the subsidence bowl suggests that it will expand farther, particularly toward the north and east; subsidence has been measured to the east in the city of Scottsdale. The extent of land subsidence to the south into the town of Paradise Valley, however, is not known. There is insufficent data on compaction and material properties of the subsurface to fully evaluate the potential of future land subsidence in northeast Phoenix; however, given known thicknesses of alluvium and present subsidence rates near the center of the subsidence bowl, more than 9 feet of land subsidence is possible if this area is completely dewatered.

The apparent lack of significant subsidence near the northern cone of depression of water levels may be due to the slow draining of the 200-foot-thick clay layer. Greater subsidence in this area will probably occur as water levels reach the base of the clay unit.

SUBSURFACE CONDITIONS

Well-drilling records and gravity data provide the basis for a depth to bedrock map (Figure 4). The map shows the relationship of past and potential land subsidence and earth fissuring to the buried bedrock topography.

The underground bedrock slopes gently toward the northeast from the Phoenix Mountains. The inner part of this area is buried less than 500 feet, and extends at least 2.5 miles into the Paradise Valley basin, with a series of hills and ridges with relief of 100-300 feet (Figure 4). The buried bedrock features follow the same NE-SW direction as the foliation and topographic expression in the adjacent Phoenix Mountains. One can visualize the buried bedrock topography as that which would exist if the present Papago Park (three miles SE of the Phoenix Mountains) were buried beneath 300-500 feet of silt, sand, and gravel.

Bordering the inner surface, is an outer, more deeply buried, low-relief topography, sloping gently northeastward at a depth of 500-1,000 feet. A major NW-SE basin and range fault separates this gently sloping surface from thick deposits of consolidated sediments.

The subsurface geologic conditions control patterns of water-level decline and land subsidence. Maximum subsidence and water-level decline have been on the deeper outer surface; whereas minimal subsidence and little or no water has been obtained from wells drilled on the shallow buried inner surface. Subsidence generally increases wherever the thickness of alluvium increases.

Gravity data indicate that a small bedrock hill underlies the fissure at a depth of about 150 feet, with at least 100 feet of relief (Figure 5C). Differential compaction induced by dewatering of sediments across this buried knoll was sufficient to cause ground failure. Continued differential subsidence has been measured (April 1981 to April 1982) along 40th Street between Shea Boulevard and Cactus Road, with as much as 0.17 feet of subsidence south of the fissure (Figure 5B). The striking similarity between the

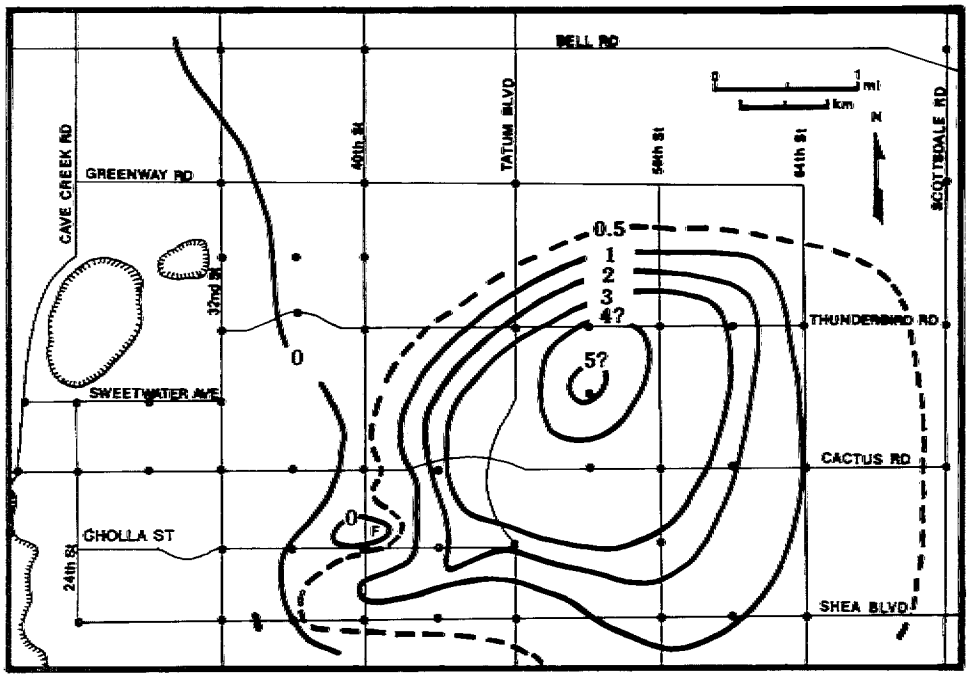

Figure 3. Land subsidence (in feet), northeast Phoenix from 1962-1982. "F" indicates location of fissure. Dots indicate locations of city benchmarks.

subsidence curve and an interpreted depth-to-bedrock profile along 40th Street supports the argument that fissuring is associated with the crests of buried hills. On the basis of the subsidence profile, theoretical calculations and computer modeling by Michael Larson (Figure 5A) and Dr. Donal Ragan at Arizona State University Department of Geology indicate that the stress in the sediments over the inferred buried hill was sufficient to crack the ground surface in 1980.

Measured differential subsidence and calculated horizontal strain strongly suggest a reopening of the entire fissure. Continued displacement is indicated by small cracks that have lengthened and become more numerous in the newly constructed paved road and concrete wall across the original fissure trace. On the basis of detailed gravity traverses, a future westward extension of the fissure is probable, with less than 600 feet of eastward extension possible. Several fissures subparallel to the original could form in the vicinity of 40th Street and Lupine Avenue.

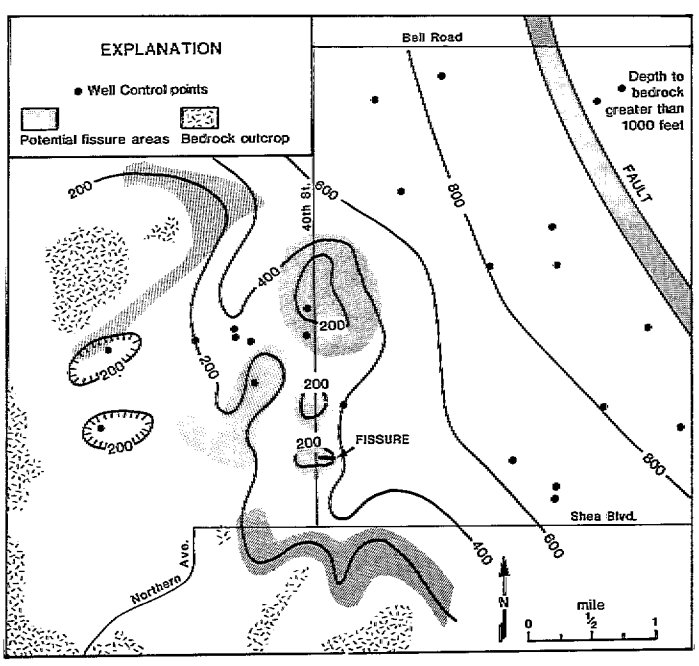

Figure 4. Estimated depth to bedrock (in feet) and potential fissure areas, northeast Phoenix. Contour interval 200 feet.

The history of fissured basins in southern Arizona bears ample evidence that the initial fissure is later followed by complex patterns of multiple fissuring. In northeast Phoenix, future fissuring may be localized in three geological settings: 1) buried bedrock topographic highs, 2) at the hinge line of subsiding areas controlled by bedrock depth, and 3) buried fault scarps. Gravity data suggest there are several buried hills between 30th and 42nd Streets, with a high probability of fissuring, particularly near those hills directly north of the fissure (Figure 4). Another area of potential fissuring is near the hinge line of subsidence between Shea Boulevard and the Phoenix Mountains east of 34th Street. Differential subsidence and fissuring are also possible across an inferred buried basin and range fault scarp in the eastern part of the study area; however, because most water-level decline and land subsidence has occurred on the upthrown rather than the downthrown fault block, fissuring seems less likely in this area at the present time.

CONCLUSIONS

Studies such as that of the northeast Phoenix area permit a better understanding of earth fissures and land subsidence phenomena. Hydrogeological and geophysical methods are now available to delimit specific areas where there is a high potential for problems due to fissuring and land subsidence. Many of these methods have been applied to the northeast Phoenix study, but as land subsidence and water-level decline continue, ongoing monitoring is necessary in order to anticipate future problems.

Similar studies could prove timely elsewhere in south central Arizona, because of the widespread distribution of ground-water development in similar geologic settings. Cooperation of city, state, and federal governments and

public education is essential if problems associated with water-level decline, land subsidence, and earth fissures are to be resolved.

For a copy of the report, make checks payable for $25.00 ($26.00 if mailed) to the City of Phoenix. Requests are taken by David Harmon, Assistant City Engineer, City of Phoenix Engineering Department, 125 East Washington St., Phoenix, AZ 85004.

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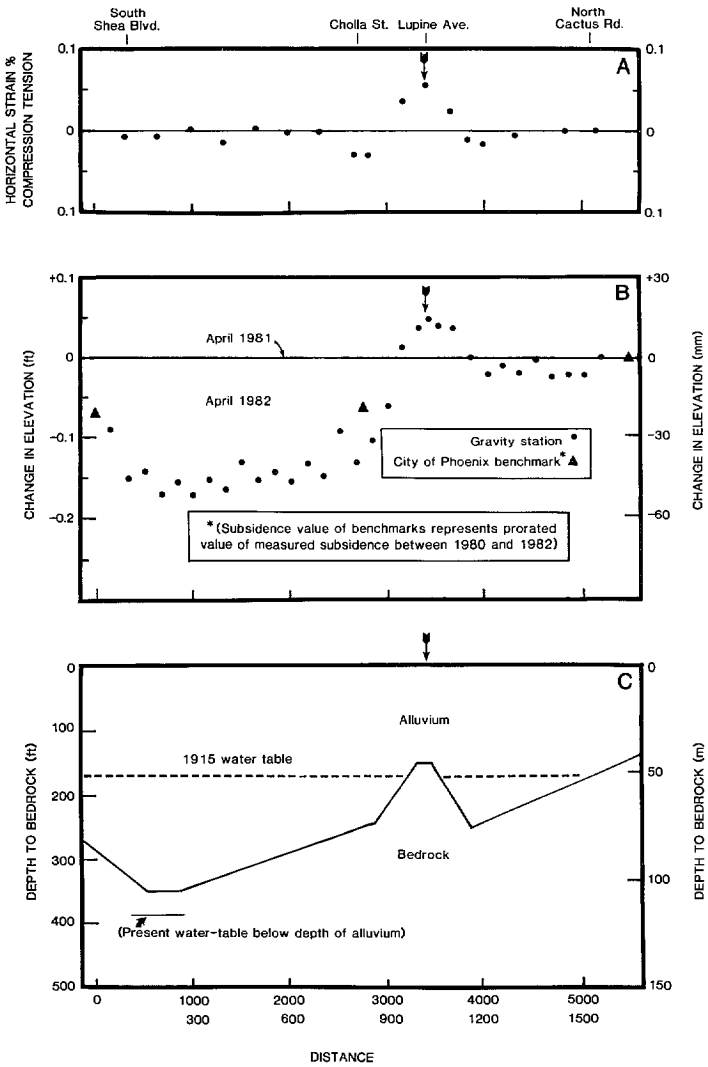

Figure 5. Surface strain, land subsidence, and depth to bedrock, 40th Street from Shea Boulevard to Cactus Road.

5A. Computed horizontal surface strain (1980) at time of fissuring.

5B. Land subsidence from April 1981 to April 1982.

5C. Interpreted depth to bedrock based on gravity data.

KRAKATAU—A Geologic Cataclysm

One hundred years ago, on August 27, 1883, the island of Krakatau exploded; then, after several days, it disappeared into the Sunda Strait near Java and Sumatra. A volcano, dormant for 203 years, had erupted, causing the two-mile-long island to collapse into the sea. All that remained after the explosion was a caldera or basin, five miles wide and more than 700 feet deep.

The volcanic blast, equal to 100-150 megatons of explosives, was heard 3,000 miles away. Seismic waves traveled several times around the earth in both directions. Four cubic miles of ash and pumice was spewed into the atmosphere (about 60 times the ejecta produced by Mount St. Helens during the early 1980s). Two islands adjacent to Krakatau were covered by 45 feet of ash and pumice, then overlain by 180 feet of lava. The heavier fallout ash blanketed 180,000 square miles; the airborne ash drifted in the stratosphere for many months, causing vivid sky scapes around the world. A sulfate/dust layer remained in the atmosphere for over five years, combining with ozone and precipitation to create a 'greenhouse' effect. As a result, a portion of solar heat was prevented from reaching the surface of the earth, and lower average surface temperatures occurred.

Loss of life from the eruption and the accompanying tsunami (the great sea wave that destroyed 300 villages and thousands of ships) is estimated to have been between 36,000 and 100,000 people.

Just as the mythical Phoenix arose from its own ashes, Anak Krakatau (child of Krakatau) first emerged as a new cone in 1927, and has since produced 30 small eruptions. Anak Krakatau is one of 500 known active volcanoes in the world today. Three of the six worst volcanic disasters in the world since the beginning of the 16th century have occurred in Indonesia (Kelut in 1586, Tambora in 1815, and Krakatau in 1883). In order of the most active volcanic history, Indonesia ranks first, Japan, second, and the United States, third.

ANNOUNCEMENT

Daniel N. Miller, Jr., resigned from his position as Assistant Secretary for Energy and Minerals at the Department of the Interior at the end of May 1983. He had occupied that position since May 1981.

In his capacity as Assistant Secretary, Miller headed up the U.S. Geological Survey, the U.S. Bureau of Mines, the Office of Surface Mining, and most recently, the Minerals Management Service.

Prior to joining Secretary Watt's team, Miller served 12 years as State Geologist of Wyoming and Director of the Wyoming Geological Survey. He also spent 11 years as Senior Exploration Geologist in the petroleum industry.

Miller will reside in Coeur d'Alene, Idaho, where he will establish a consulting service.

OPEN-FILE REPORTS: 1971-1982

In recent years, state and federal agencies have increasingly used open-file reports as a means for disseminating timely information to the public. The Arizona Bureau of Geology and Mineral Technology *(Bureau)* serves as a repository for more than 800 open-file reports by the U.S. Geological Survey, U.S. Bureau of Mines, and U.S. Department of Energy. In addition, the *Bureau* has established its own open-file system containing reports by both *Bureau* and non-*Bureau* authors. This open-file system contains 1) preliminary releases of new *Bureau* research; 2) preliminary versions of reports and maps being prepared for formal publications; 3) final reports of externally funded projects; and 4) geologic maps and reports by *Bureau* and non-*Bureau* personnel that would not otherwise be published. Many of these reports have not been edited or reviewed for conformity with *Bureau* standards.

All open-file reports are available for inspection at the *Bureau's* library in Tucson. Most of these reports are available for purchase by mail and they can also be checked out and copied at local blueprint and reproduction companies in Tucson. The titles and mail order prices of *Bureau* open-file reports completed before 1983 are listed below. The release of subsequent open-file reports will be announced in *Fieldnotes*.

†71-1 Fossils of Arizona, 1971, Wilt, J.C., 399 p.

74-1 Outcrop and surficial geology, Flagstaff area, Coconino County, Arizona, 1974, Montgomery, E.L., and others, map scale 1:24,000. $2.25

76-1 Cross sections of southern Arizona and adjacent parts of California and New Mexico, 1976, Richardson, C.B., 51 cross sections. $1.50/section

77-1 Map of published Phanerozoic age determinations in Arizona, 1977, Keith, S.B., and Reynolds, S.J., scale 1:1,000,000 (Geological Survey Branch). $1.50

77-1a Compilation of radiometric age dates for Arizona, 1977, Keith, S.B., 187 p. (Geological Survey Branch). $14.50

77-2 Landsat lineament map of Arizona with emphasis on Quaternary fractures, 1977, Lepley, L.K., scale 1:1,000,000, 30 p. (Geothermal Assessment Project). $6.25

78-1 Low-temperature geothermal reservoir site evaluation in Arizona, 1978, Hahman, W.R., 128 p. (Geothermal Assessment Project). $11.50

78-2 Quarterly progress report for period May 1, 1977-Jan. 31, 1978, 1978, Hahman, W.R., 57 p. (Geothermal Assessment Project). $8.00

78-3 The geology of Arizona: its energy resources and potential, 1978, Nations, Dale, *in* The Interstate Oil Compact Commission Committee Bulletin, v. xx, no. 2, p. 42-53. $1.50

78-4 Skylab lineament map of Arizona with tectonic model and exploration guide for geothermal resources, 1978, Lepley, L.K., 10 plates, scale 1:500,000, 35 p. (Geothermal Assessment Project). $20.50

78-5 Potential of geothermal energy in Arizona, 1978, Hahman, W.R., and others, 147 p. (Geothermal Assessment Project). $12.50

79-1 A study of uranium favorability of Cenozoic sedimentary rocks, Basin and Range Province: Part 1, general geology and chronology of pre-late Miocene Cenozoic sedimentary rocks, 1979, Scarborough, R.B., and Wilt, J.C., 101 p. (Geological Survey Branch). $12.00

79-2 Geothermal reservoir site evaluation in Arizona, semiannual progress report for the period July 15, 1978-Jan. 15, 1979, 1979, Hahman, W.R., 91 p. (Geothermal Assessment Project). $9.50

79-2a An overview of the geothermal potential of the Springerville area, Arizona, 1979, Stone, Claudia, 26 p. (Geothermal Assessment Project). $3.75

79-2b A progress report of geothermal investigations in the Clifton area, 1979, Witcher, J.C., 16 p. (Geothermal Assessment Project). $2.25

79-2c A preliminary report on the geothermal energy potential of the Safford Basin, southeastern Arizona, 1979, Witcher, J.C., 31 p. (Geothermal Assessment Project). $4.50

79-2d A preliminary study of the geothermal potential of the Tucson metropolitan area, 1979, Witcher, J.C., 19 p. (Geothermal Assessment Project). $3.00

79-3 Report on the general geologic history of the Mesa NTMS Quadrangle with accompanying 1:250,000 compilation maps of geology and metallic mineral occurrences, 1979, Scarborough, R.B., 76 p., two maps (Geological Survey Branch). $11.00

79-4 GSA field trip guide to coal deposits of Black Mesa and geologic road log between Phoenix and Page, Arizona, 1979, Peirce, H.W., and others, with map and cross section, 45 p. (Geological Survey Branch). $4.50

79-5 Proven, potential and inferred geothermal resources of Arizona and their heat contents, 1979, Witcher, J.C., 65 p., one plate (Geothermal Assessment Project). $9.50

†Report not available through mail.

*Report available from Dr. D.H. White, Department of Chemical Engineering, University of Arizona, Tucson, AZ 85721.

79-6 Geothermal energy in Arizona (excerpt from Geothermal Energy, v. 7, no. 11), 1979, Hahman, W.R., p. 7-18 (Geothermal Assessment Project). $1.50

79-7 Geothermal studies in Arizona with two area assessments: progress report for the period January 16, 1979-November 1, 1979, Hahman, W.R., 173 p. (Geothermal Assessment Project). $13.50

*79-8 Geothermal development plan, Maricopa County, 1982, Goldstone, L.A., and White, D.H., 64 p. (Geothermal Commercialization Project, Department of Chemical Engineering, University of Arizona).

*79-9 Geothermal development plan, Pima County, 1982, Goldstone, L.A., and White, D.H., 55 p. (Geothermal Commercialization Project, Department of Chemical Engineering, University of Arizona).

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*79-11 Geothermal development plan, Pinal County, 1982, Goldstone, L.A., and White, D.H., 35 p. (Geothermal Commercialization Project, Department of Chemical Engineering, University of Arizona).

†79-12 Preliminary geothermal assessment of the Willcox Basin, 1979, Jones, N.O., and Campbell, Alice, 33 p., seven plates (Geothermal Assessment Project).

79-13 Preliminary geothermal assessment of the Hyder area—with a section on hydrology, 1979, Jones, N.O., and Campbell, Alice, 33 p., eight plates (Geothermal Assessment Project). $9.50

79-14 Preliminary geothermal assessment of the Harquahala-Tonopah area, 1979, Jones, N.O., 43 p., eight plates (Geothermal Assessment Project). $11.25

79-15 Preliminary geothermal assessment of the Big Sandy Valley, Mohave County, Arizona, 1979, Campbell, Alice, and Jones, N.O., 26 p., six plates (Geothermal Assessment Project). $7.50

79-16 Springerville-Alpine geothermal project: results of heat-flow drilling, 1979, Stone, Claudia, 21 p. (Geothermal Assessment Project). $3.00

79-17 Preliminary assessment of the geothermal potential of the northern Hassayampa Plain, Maricopa County, Arizona, 1979, Stone, Claudia, 42 p. (Geothermal Assessment Project). $6.00

79-18 The geothermal potential of IBM plant site area, Tucson, Arizona, T. 15-16 S., R. 15 E., 1979, Wicher, J.C., 26 p. (Geothermal Assessment Project). $3.75

80-1 Arizona geothermal energy appraisal studies, 1980, Hahman, W.R., ed., 144 p. (Geothermal Assessment Project). $12.00

80-1a Heat flow and the thermal regime in the Clifton, Arizona area, 1980, Witcher, J.C., and Stone, Claudia, 28 p. (Geothermal Assessment Project). $4.00

80-1b Potential for geothermal desalination in the southwestern U.S., 1980, Swanberg, C.A., and Rybarczyk, S.M., 10 p. $1.75

80-1c Analyses of short-term microearthquake activity related to potential geothermal areas in Arizona, 1980, Sbar, M.L., 14 p. (Geothermal Assessment Project). $2.25

80-2 Geologic map and cross section of the Bill Williams district, Yuma County, Arizona, 1980, Wicklein, P.C., two maps, scale 1:24,000. $3.75

80-3 Fossils of Arizona: a selected bibliography, 1980, Rumery, J.V., 46 p. $6.75

80-4 Springerville geothermal project—geology, geochemistry, geophysics—final report, 1980, Stone, Claudia, 26 p. (Geothermal Assessment Project). $4.00

80-5 Geothermal resource evaluation at Castle Hot Springs, Arizona, 1980, Sheridan, M.F., Satkin, R.L., and Wohletz, K.H., 51 p. (Geothermal Assessment Project). $7.50

80-6 Preliminary assessment of the geothermal potential at the Papago Farms, Papago Indian Reservation, Arizona, 1980, Stone, Claudia, 62 p. (Geothermal Assessment Project). $8.00

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*80-10 Geothermal development plan, northern Arizona counties, 1980, Goldstone, L.A., and White, D.H., 66 p. (Geothermal Commercialization Project, Department of Chemical Engineering, University of Arizona).

80-12 Preliminary geothermal assessment of the Verde Valley, Arizona, with a section on hydrology, 1980, Hahman, W.R., and Campbell, Alice, 21 p., nine plates (Geothermal Assessment Project). $8.75

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Helium Resources continued

strata of the Mogollon slope to the south and southwest (Figure 1). The saddle separates the structurally lower Black Mesa Basin to the northwest from a structural low to the southeast that may be part of the Gallup sag (Peirce and others, 1970). Within this regionally defined saddle are a number of smaller uplifts of low relief, some of which form traps for helium accumulation. The geometry of subsurface structures in the helium-producing area is known primarily from drill hole data (Dunlap, 1969; Peirce and Scurlock, 1972; Conley and Scurlock, 1976).

The Pinta Dome helium field occurs within the Pinta anticline, an east-west-trending, doubly plunging structure with about 100 feet of relief (Figure 3). Dips on the flanks of Pinta Dome are typically 0.5–1.5 degrees. The Pinta Dome fault offsets the northeast flank of the dome.

A northwest-trending anticline about three miles east of Pinta Dome forms the Navajo Springs helium field. This doubly plunging anticlinal structure has about 100 feet of structural relief, and is terminated northward by the Navajo Springs fault. The small East Navajo Springs helium gas field, about five miles east of the Navajo Springs field, lies immediately northeast of the Kirby fault (Figure 3).

ORIGIN OF HELIUM

Terrestrial helium has two sources: 1) primordial helium that was incorporated into the Earth at the time of its formation and is now derived from sources deep within the Earth, and 2) radioactive decay of uranium and thorium which are concentrated in the Earth's crust. Helium is composed of two isotopes: helium 4, which is produced by radioactive decay, and helium 3, which was created before the Earth formed and was incorporated into the Earth during its formation. High ratios of helium 3 to helium 4 in some hot springs associated with volcanic activity indicate the presence of a significant component of primordial helium probably derived from the mantle. Low ratios of helium 3 to helium 4 found in most, if not all, natural gas fields, indicate that this helium was primarily derived from radioactive decay of uranium and thorium.

The Coconino Sandstone contains very little uranium and thorium, and consequently could not be a significant source of helium in the Pinta Dome-Navajo Springs area. One possible source for the helium is the Precambrian crystalline basement beneath the sediments (Peirce and Scurlock, 1972). There is little information on the detailed nature of these rocks, but they include granitic rocks that likely contain small amounts of helium-producing radioactive elements. A problem with this potential source is that the Supai Formation, separating crystalline basement from Coconino Sandstone, contains hundreds of feet of impermeable evaporites. However, Supai evaporites wedge out rapidly to the northeast and northwest. Helium originating from the Precambrian basement could have migrated upward to the Coconino Sandstone where Supai evaporites are absent, and then migrated up-dip through Coconino Sandstone to structural traps above evaporitic Supai sediments. The presence of helium in clastic sediments between Supai evaporites may also result from up-dip lateral migration from evaporite-free areas. Fracturing may also permit upward migration of helium through evaporitic strata (Peirce and others, 1970).

Alternatively, helium may have originated from sediments overlying the Coconino Sandstone. Gamma ray logs from drill holes indicate that the Shinarump and Petrified Forest Members of the Chinle Formation, and the lower part of the Moenkopi Formation, contain significant amounts of radioactive material. In most areas, helium from these possible helium-source rocks would have had to migrate downward through relatively impermeable strata to reach the Coconino Sandstone. However, faulting has locally brought these potential helium-source rocks down and into contact with the reservoir rocks, perhaps eliminating this access problem (Dunlap, 1969).

HELIUM PRODUCTION IN ARIZONA

In 1961 Kerr McGee Corporation and Eastern Petroleum began production of helium from the Pinta Dome field near Holbrook, and opened the world's first commerical helium extraction and purification plant. The Navajo Springs and East Navajo Springs helium fields began production in 1964 and 1969, respectively. One well in the Teec Nos Pos oil and gas field produced helium during 1968 and 1969. Production of helium gas from all these fields ended by 1976 because the gas fields had either been depleted or had become unprofitable due to a large drop in helium prices. No helium has been produced in Arizona since this time (Figure 4).

Statistics compiled by the Arizona Oil and Gas Conservation Commission indicate that Arizona's gross helium gas production has been 9,238 million cubic feet, almost all of which came from the Pinta Dome-Navajo Springs area. Assuming an average helium content of 8.5 percent, about 785 million cubic feet of helium was produced from Arizona, valued at an estimated $27 million (based on the 1961 price of $35 per thousand cubic feet; U.S. Bureau of Mines, 1980).* This amount of production is comparable to the total annual world helium consumption during the early 1970s.

*The 1980 government price (average value) for helium was $35 per thousand cubic feet; the 1980 private industry price was $22.50 (U.S. Bureau of Mines, 1980).

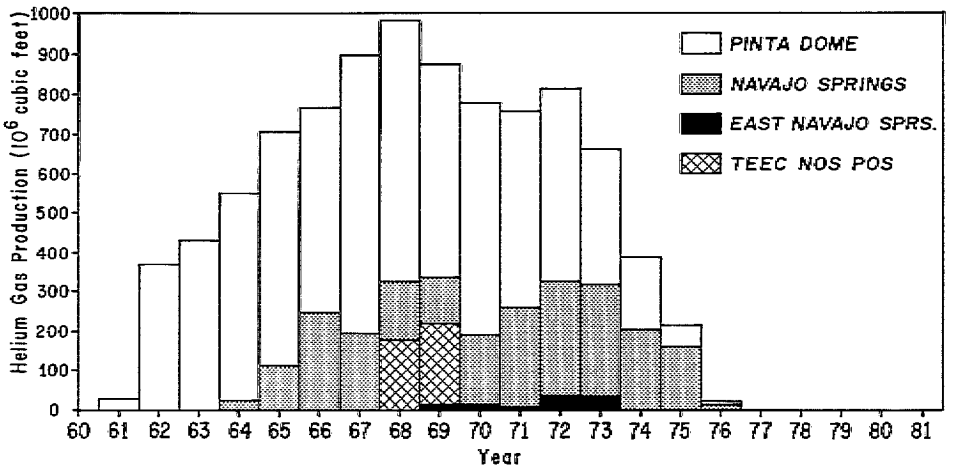

Figure 4. Annual helium production from helium-gas fields in Arizona (data from Arizona Oil and Gas Conservation Commission).

FUTURE OF ARIZONA'S HELIUM INDUSTRY

If crystalline rocks of the Defiance uplift are the source of the helium in the Pinta Dome and related helium-gas fields, then many other areas around the Defiance uplift may be promising targets for helium exploration. Much of the area around the Defiance uplift is within the Navajo Indian Reservation, and has had little, if any, exploration for helium. Wells drilled for helium exploration in this area generally penetrate only to the top of the Coconino Sandstone, although helium has also been reported from the underlying Supai Formation. It thus seems probable that other helium deposits await discovery in Arizona.

The cost of extracting helium from natural gas containing about 0.5 percent helium is about $13 per thousand cubic feet. Arizona helium can be extracted for significantly less since its concentration is much higher.

Natural gas reserves are being depleted at such a rapid rate that, if present trends prevail, there will be very little helium gas left within 30-40 years. When the demand for helium first exceeds the supply from natural gas, demand can be met with helium now in the federal storage reservoir. However, even this will run out eventually. When both natural gas reserves and the federal storage reservoir are depleted, the value of helium may increase a hundred to a thousand times. At such prices, the smallest helium gas fields would become highly valuable, and the Arizona helium industry could suddenly recover from decades of inactivity.

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Fieldnotes

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DEC 21 1983

The Future of the United States Copper Industry:

Part One. The Production Side

by Richard T. Newcomb

Richard Newcomb, a Professor in the Mineral Economics Program of the Department of Mining and Geological Engineering at the University of Arizona since 1982, received his PhD in economics from the University of Minnesota. He has taught at the Pennsylvania State University, the University of Pittsburgh, and West Virginia University, and has published numerous articles on technological change in the materials industries and on the economics of principal energy and mineral commodity markets.

Is the U.S. losing its comparative advantage in copper metal production to other countries? A large and growing bibliography of studies and commentaries can be cited to support such a hypothesis (Sousa, 1981); Commodities Research, Ltd., 1976 and 1982; Consolidated Gold Fields, Ltd., 1979; Dresher, 1978; Harbridge House, Inc., 1977; Arthur D. Little, 1978; and Tomimatusu, 1980). In brief, these studies suggest U.S. copper producers have six disadvantages over the long term on the *supply* (production) side: (1) the depletion of high-grade domestic ores, (2) the rise in U.S. wage rates and other production costs, (3) the more recent applications of new technology outside the U.S. where metals-industry growth has been so much more rapid, (4) prejudicial U.S. government regulation of safety and the environment, (5) the mismanagement of federal lands and stockpiles, and (6) high levels of domestic taxation. On the *demand* (consumption) side, the studies suggest three additional problems for the copper industry: (1) cheaper and lighter weight materials developed in the communications, transportation, and construction markets offer competition to the copper industry, (2) government policies prevent the most agressive U.S. firms from capturing a growing share of their home or international markets, and (3) U.S. producers' prices have been deliberately depressed.

In Part One of this paper, I review the industry's problems on the supply side. In Part Two, which will appear in a future issue of *Fieldnotes*, I will analyze the more complex and generally neglected demand-side problems, relying on conventional commodity market analyses of short-term price fluctuations and long-term trends for insights into industry and government behavior. My conclusions lead to a somewhat different view of world copper's future, and the U.S. role, than conventional wisdom forecasts.

The domestic copper industry is apparently in serious trouble, and the problems, by all accounts, will not go away quickly. The most recent closures of mines and smelters during the current depressed market conditions, while net imports of metal and mill products continue to rise, give dramatic attention to short-run difficulties faced by industry. However, the long-term nature of U.S. comparative disadvantages is indicated by the decline of U.S. production over the past ten years, while the rest-of-the-world's markets and industry boomed. U.S. copper firms are not alone in their concerns. Because price trends signal the potential reduction of copper metal productive capacity and the attendant loss of domestic resource values, they raise strategic questions for major consumers of copper in the communication, transportation, and defense industries.

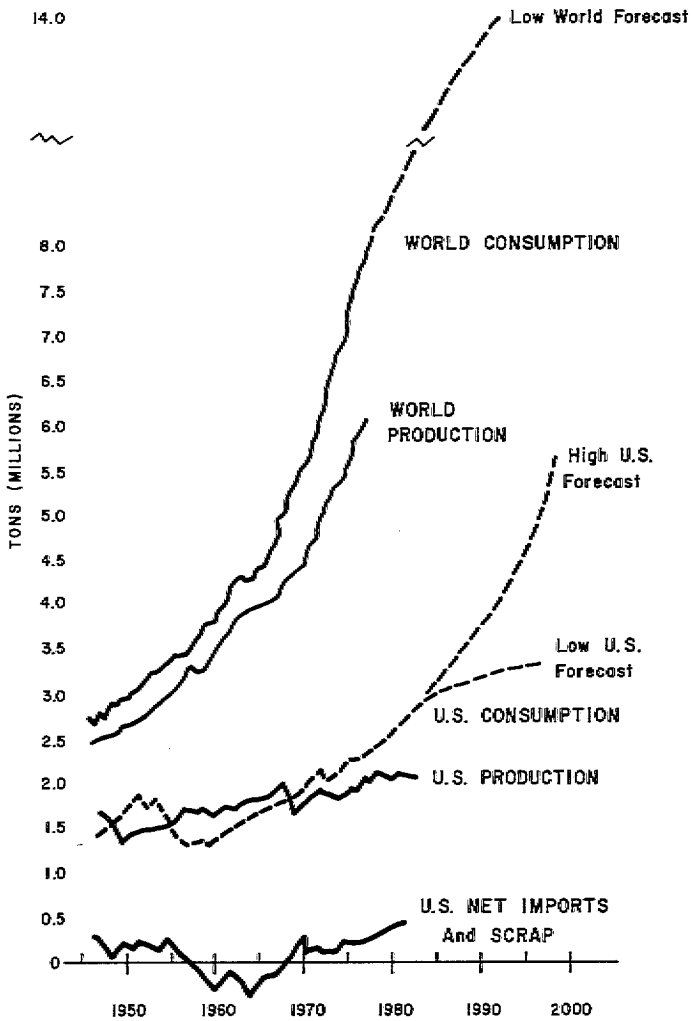
The U.S. copper industry consists of hundreds of firms. One-third of these firms, engaged in mining and smelting activities located largely in the western U.S., employ 90,000 persons and contribute $3-4 billion to the Gross National Product (GNP) annually. The remaining two-thirds of U.S. copper firms are brass and wire mills whose fabricating activities are concentrated in New England and the Middle Atlantic states. This paper focuses upon the future prospects of the twelve larger, integrated firms, their 26 mines and 16 smelters which produce almost all the country's primary metal, and their subsidiaries which supply a significant portion of the refined metal and semi-fabricated brass and wire products. These firms, by their activities, account for most of the copper resource values in the U.S. The fact that U.S. copper ore reserves are located in the states of Arizona, Montana, Utah, and New Mexico makes the industry of special interest to the Southwest.

U.S. DOMESTIC RESOURCES, DEPLETION, AND RISING COSTS

In the view of many, U.S. copper firms are casualties of high-grade ore depletion and rising costs of capital and labor. Both effects diminish the ability of U.S. firms to compete with producers abroad who are mining richer orebodies and experiencing lower labor and capital costs. This explanation is consistent with the observable trends in U.S. production of primary metal from 1945 to 1980 (Exhibit 1A). U.S. primary production has virtually stagnated at about two million tons while domestic consump-

EXHIBIT 1A

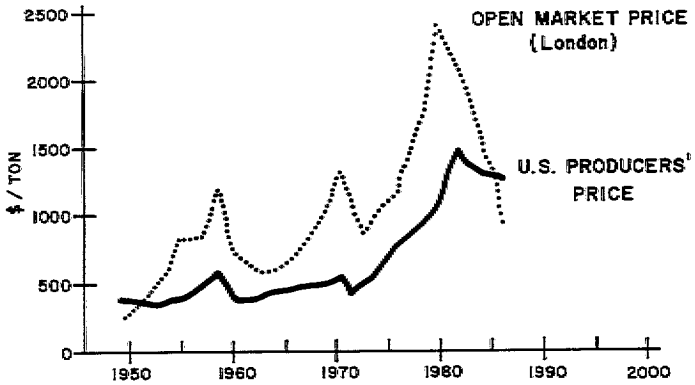
TRENDS IN WORLD AND U.S. REFINED COPPER PRODUCTION AND CONSUMPTION, 1945-2000



Source: U.S. Bureau of Mines, *Minerals Yearbook.*

EXHIBIT 1B

TRENDS IN WORLD AND U.S. REFINED COPPER PRICES 1954-1980
(in dollars per ton)



Source: U.S. Bureau of Mines, *Mineral Facts and Problems* and *Minerals Yearbook.*

tion has grown at most by about a million tons. The difference is imports and scrap. U.S. growth is much slower than consumption abroad. In contrast, demands outside the U.S. rose impressively from one million tons to almost five million tons, with the result that the U.S. share of world consumption declined from three-fourths in 1950 to one-fourth in 1974. Throughout the 30-year period world demands generally outpaced capacity growth. This forced open-market prices (Exhibit 1B) to rise in free metal exchanges, such as London's, far higher than the U.S. Producers' Prices, the price per pound charged by domestic producers, usually on longer contract terms. As a result, the U.S. was a net exporter of metal and scrap through the 1960's, although the quantities were small and few brass mill products were permitted by the major receiving countries. Since 1970 the excess of U.S. consumption over production has had to be met by imports and scrap.

The theory of competition suggests that the intersection of supply and demand determines both market prices and quantities of copper mined in producing regions and sold in consuming centers. Exhibits 2 and 3 illustrate the changes

EXHIBIT 2

PRINCIPAL WORLD SUPPLIES AND DEMANDS FOR COPPER BY MAJOR PRODUCING AND CONSUMING REGIONS, 1950

(in million tonnes)

Supply	Demand Regions	(NA)	(LA)	(PB)	(Af)	(So)	(Eu)	(Ot)	Total Supply
(NA) North America		1.0					0.2		1.2
(LA) Latin America		0.4							0.4
(PB) Pacific Basin									
(Af) Africa							0.5		0.5
(So) Soviet						0.1			0.1
(Eu) Europe									
(Ot) Other		0.3		0.1			0.1		0.5
Total Demand		1.7		0.1		0.1	0.8		2.7

Source: Derived from U.S. Bureau of Mines, *U.S. Mineral Yearbooks*

EXHIBIT 3

PRINCIPAL WORLD SUPPLIES AND DEMANDS FOR COPPER BY MAJOR PRODUCING AND CONSUMING REGIONS, 1974

(in million tonnes)

Supply	Demand (NA)	(LA)	(PB)	(Af)	(So)	(Eu)	(Ot)	Total Supply
(NA) North America								
U.S.	1.7							1.7
Can.	.6					.3		.9
(LA) Latin America	.2	.6			.2	.2		1.2
(PB) Pacific Basin			.8					.8
(Af) Africa	.3			.8		.4		1.5
(So) Soviet					1.1			1.1
(Eu) Europe								
(Ot) Other	.4					.3		.7
Total Demand	3.2	.6	.8	.8	1.3	1.2		7.9

Source: Derived from U.S. Bureau of Mines, *U.S. Mineral Yearbooks* and *Mineral Facts and Problems.*

in production and consumption volumes which determined the flows of trade in world copper from 1950 to 1974. Thirty years ago North America and Europe provided most of the consumption, and North and Latin America most of the production, in a total world use of 2.7 million tons. By 1974, the Pacific Basin, largely Japan encouraging production from Australia, New Guinea, and the Philippines, had become a growing and important copper mining and refining center. These and the expanding Common Market Community, largely Europe encouraging production from Latin America and Africa (Zambia, Zaire, and South Africa), accounted for most of the 5.2 million tons of increased copper use. In other words, the U.S. accounted for little of the world market growth to 7.9 million tons.

EXHIBIT 4

U.S. COPPER YIELDS, PRICES, AND LABOR EARNINGS PER HOUR, 1910-1979

Year	Ave. Cu. Yield %	Ave. Producers Price Current $	Ave. Producers Price Constant $ (1979)	Hourly Earnings Mining $	Hourly Earnings Other $	Total Earnings ($ millions) $	Total Earnings ($ millions) $ (1977)	Real Earnings $/ton (1967)
1910	**1.88**	.13	**100.0**	NA	NA	NA	NA	NA
1950	**.89**	.21	**64.8**	NA	NA	85	132	**145**
1960	**.73**	.32	**78.9**	NA	NA	137	160	**148**
1970	**.59**	.58	**108.0**	3.93	3.35	267	215	**125**
1979	**.49**	.93	**93.3**	9.53	6.69	537	205	**129**

Source: Sousa (1981), *The U.S. Copper Industry*

Ore-grade depletion is evidenced by the fall in average yields of U.S. mines (Exhibit 4). From 1910 to 1979 average grades dropped 75 percent, lowering yields from nearly two percent to one-half percent. Currently, the U.S. is mining ores containing less than 0.70 percent copper, although somewhat lower grades are minable in years when prices are high. These low grades must be compared to those in Africa, which are as high as 3.9 percent, or those in Latin America, which average above 1.0 percent (Exhibit 5). Most observers accept the claim that U.S. ore-grade depletion explains the observed shift of the copper industry's mining activities from the U.S. to other parts of the world in recent years. Real wages in the copper industry rose twice as fast as manufacturing wages, accompanying the decline in ore grades in the U.S. Since 1970, hourly earnings rose from $3.93 to over $9.53 (Exhibit 4). Present U.S. wage levels are five to fifteen times higher than those of competing countries. Energy and waste disposal problems also rose as ore grades fell, because of the added costs of mining and beneficiating increasing tonnages of ore to obtain a given metal output. The energy intensity of these activities in the U.S. rose 10 percent in mining and 20 percent in ore processing to a total of 52,000 Btu per pound of copper produced. Without extensive analysis, the implications of these data are that ore-grade depletion in the U.S. has reduced U.S. producers to mining reserves that cost more to develop than those of other regions. Exhibit 5 shows that in the last fully reported years U.S. production costs averaged 61 to 69 cents per pound. These must be compared to generally lower Canadian costs of 39 to 58 cents per pound, to African costs of 42 to 75 cents per pound, to Latin American costs of 43 to 56 cents per pound, and to Pacific Basin costs of 19 to 57 cents per pound.

Exhibit 6 presents recent forecasts for the world and the U.S., based on the trends observed from 1950 to 1980. If the historic relationships between declining ore grades and rising energy costs were to continue through the year 2000, energy costs would double. U.S. wage rates are also expected to rise faster than those abroad, and U.S. ore grades are expected to fall further. Thus it has been surmised that U.S. producers will continue to smelt a declining share of total world output.

EXHIBIT 5

CALCULATED AVERAGE GRADE OF COPPER RESERVES AND AVERAGE OPERATING REAL COSTS PER TON FOR MAJOR COPPER REGIONS, 1976-1978

	Percent grade 1977	Cents per pound (in 1977 dollars) 1976	1977	1978
NORTH AMERICA				
United States	.71	**61**	**69**	66
Canada	.70	**58**	40	**39**
LATIN AMERICA				
Chile	1.11	55	44	**43**
Peru	1.07	**56**	44	47
PACIFIC BASIN				
Australia	2.58	**57**	53	51
Philippines	.54	46	51	48
Papua New Guinea	.47	39	**19**	40
AFRICA				
Zaire	3.90	69	**75**	74
Zambia	3.06	66	69	69
South Africa	.71	**42**	48	44

Source: Sousa (1981), *The U.S. Copper Industry*

EXHIBIT 6

FORECAST WORLD SUPPLIES AND DEMANDS FOR COPPER IN 2000, ASSUMING OPTIMISTIC CONDITIONS

(in million tonnes, by major region)

Supply	Demand Regions (NA)	(LA)	(PB)	(Af)	(So)	(Eu)	Total Supply
(NA) North America	**3.9**					**1.5**	**5.4**
(LA) Latin America	0.2	2.0	2.9		2.2	0.9	8.2
(PB) Pacific Basin			1.5				1.5
(Af) Africa			1.0	1.3		3.3	5.6
(So) Soviet					2.7		2.7
(Eu) Europe						0.5	0.5
Total Demand	**4.1**	2.0	5.4	1.3	4.9	6.2	**23.9**

NA is Canada and U.S.
LA includes Mexico and North American Latin Republics.
PB includes Asia and Oceana (Australia and New Zealand).
AF includes Middle-East oil producers.
So includes Eastern European Soviet Bloc countries except Yugoslavia.
Eu includes United Kingdom and free Europe plus Yugoslavia.

Source: Leontief and others (1982), *Nonfuel Minerals Forecast.*

U.S. copper firms have also been alarmed at the manner in which the Environmental Protection Agency (EPA) has mandated improvements in mining and smelting operations for the control of sulfur oxide (SOx) emission. Exhibit 7, from Rieber (1982), lists the six major U.S. producers and their mining and smelting capacities, most of which are in five western states. The advanced ages of the furnaces, which average 57 years, are evident. Sousa (1981) estimates it has cost $724 million to date and will cost an additional $1.73 billion to meet ultimate EPA standards in 1988 (Exhibit 8). If so the cumulative costs may reach 10 cents per pound. The copper industry notes that the added costs of smelter control may well outweigh the

EXHIBIT 7

MAJOR U.S. FIRMS' MINE PRODUCTION, SMELTER CAPACITY AND AVERAGE SMELTER AGE

(in short tons of copper, 1979 and 1981)

Company	1979 Mine Output[1]	% U.S.	No. Mines	1981 Smelter RC[2]	% U.S.	No. Units	Ave. Age[3]
Kennecott	387,774	24	4	590,000	30	4	52
Phelps Dodge	342,900	22	4	654,000	34	4	35
Newmont	155,135	10	2	200,000	10	1	24
Anaconda	152,077	10	2	--	--	1	74
Duval	132,255	8	3	--	--	-	--
ASARCO	96,333	6	4	280,000	14	3	78
Subtotal	1,266,474	80	19	1,724,000	88	13	57
Others[4]	324,747	20	10	247,000	12	3	42
Total U.S.	1,591,221	100	29	1,971,000	100	16	50

[1] Short tons of metal annually.

[2] Rated Capacity in 1981; Anaconda's smelter closed in 1980.

[3] Unweighted by tonnage capacities. Includes one oxygen-process facility less than ten years old.

[4] Anamax, Cyprus, and Inspiration in the West; White Pine and Cities Service in the East.

Source: Rieber (1982), *Smelter Emission Controls.*

benefits of conversion to new standards at old facilities, forcing the replacement or relocation of some. Dorenfeld and others (1981) estimate that compliance may add 5-15 cents per pound to U.S. copper production costs. The implication is that, because of current disadvantages in ore grades and production costs, U.S. mines cannot possibly compete with new mines and smelters elsewhere in the world. Therefore, one can predict the closing of southwestern U.S. mines over time, and the increasing reliance of the eastern domestic copper industry on foreign ores or metal. As a matter of fact, such implications are not warranted from the economic analysis of the industry. On the contrary, despite continued declines in ore grades and rising production costs, U.S. domestic reserves will be competitive with ores mined abroad for many years in the future.

EXHIBIT 8

ACTUAL AND PROJECTED CAPITAL COSTS OF CONTROL, U.S. COPPER INDUSTRY

(in $ millions)

	Actual Costs 1973-78	Projected Costs 1979-88
Air Pollution Control	670	1,039
Worker Safety	27	225
Noise Abatement	--	150
Water Control	27	316
TOTAL	724	1,730

Source: Sousa (1981), *The U.S. Copper Industry*

TECHNOLOGICAL CHANGE

One reason for the economic viability of southwestern U.S. reserves is that technology and economic conditions do not stay constant, but change to offset ore-grade depletion effects, even to the extent of making geologically inferior ores more economic to mine than ores of higher grades. For example, in the 19th century, new U.S. underground mining and beneficiation equipment enabled the Calumet Mining Company of Michigan to compete successfully with other U.S. and European smelters despite lower average ore grades. Again, in the early 1900's, western firms developed porphyry copper deposits lower in grade than the type of deposits being mined elsewhere, such as in Michigan's "copper country." The switch to different deposit types of inferior ore grades was accompanied by the successful application of open-pit methods. Metallurgical innovations were also necessary and important; the effect of new techniques in this case offset ore-grade depletion. So great were the comparative advantages of Jackling's Butte, Montana operation that his integrated firm could ship metal much longer distances to its eastern brass and wire mills for refining and fabrication than could closer competitors. His mills could also undersell imports produced from ores of much higher grades. By 1950 the very high grade Michigan ores, which had achieved prominence in the 1890's, were facing extinction, yet the U.S. had become the dominant copper-producing region, accounting for two-thirds of the world's primary metal output. According to Sir Ronald Prain (1975), certain inferior-grade copper deposits in many parts of the world continue to be among the lowest cost producers of metal. It is noteworthy that some of the most recently established copper mines, such as in the Philippines and New Guinea, are mining copper with grades significantly below either American or African mines. Low-grade copper ores in Canada are produced by many mines that have low production costs; their comparative advantage lies in the production of high-valued by-products.

Innovations in equipment have increased the productivities of labor more than the rise in real wages. This has allowed some mines with low-grade ores to remain competitive. Thus, falling grades have not always meant lower recoveries of metal in ore per man-hour. Similarly, higher real wage rates do not always lead to higher wage costs per ton. More capital-intensive methods can offset higher wages when capital is substituted for labor. U.S. producers' copper prices showed no rise in real terms for over 30 years despite the rise in U.S. real wages. Again, while total labor earnings rose $73 million from 1950 to 1979, real labor earnings per ton fell from $145 to $129 per ton (Exhibit 4) simply because labor productivities rose so rapidly. This permitted U.S. metal prices to remain lower than world market prices notwithstanding rising wages and the increasing reliance on copper from lower-grade U.S. deposits. Even today, the capital costs of expanding U.S. mines are estimated to be half those of developing new mines abroad. Lower capital costs in the U.S. offset higher cutoff grades in new mines abroad, where new mines must force higher world prices. Thus technological changes, falling shares of labor in product value (Exhibit 4), and lower capital costs explain some of the observed differences between market prices on the London Metal Exchange (LME) and U.S. producers' prices since 1950 (Exhibit 1B). The latter have been significantly below the former over the past thirty years.

Infrastructure facilities, such as rail lines and docks, are another major contributor to higher incremental costs abroad than in the U.S. Considerable time is required for the variable factors of lower wages and better grades to

offset high, fixed costs, making any direct correlation between observed grades and regional prices misleading. In the long run, ore-grade depletion triumphs over technical change in any extractive region, so that long-term industry expectations are always of rising prices. As copper prices rise, however, the substitution of more abundant materials will increase. Long before the physical exhaustion of reserves, demands for copper will cease to grow. This diminution in growth is most evident in the most highly developed countries. Thus, in the United States, aluminum and other materials are rapidly replacing much copper in electrical transmission systems or in automobile radiators, and polyvinyl chloride tubing is replacing some copper in construction. In Japan and Europe, such substitutions are less evident, while in under-developed regions, they are rare.

Innovations affecting the material costs of users are not limited by any means to extraction or processing. Changes in transportation technologies and the simple differential growth of demands in different locations also affect international market shares. In light of the above, recently expressed concerns about the disadvantages of "domestic" copper firms which compete with "foreign" companies can be seen as confused statements that fail to account for all factors influencing comparative advantages. Indeed, historically, U.S. copper firms have always been prominently involved in world copper trade. In the 1850's when the U.S. smelted virtually none of its own copper, Japan was a major producer and shipped metal to London as the mines of Cornwall, England became depleted. In the 1900's Japan became a copper metal importer. In 1982 Japan is again a major metal producer, but without any domestic production of copper ores. Recently, Japan began smelting western U.S. ores. "Domestic" U.S. firms have also been involved significantly in the foreign production of ores and in the international trade of copper products. The major U.S. firms, with their subsidiaries, helped develop many of the world's copper reserves in Canada, Mexico, Africa, and Latin America, including mines now operating in Chile, Peru, and Brazil. By 1900 the U.S. industry was a major exporter of copper products, and its importance grew as U.S. firms expanded abroad. Much of this international character would remain today were it not for the confiscations of U.S. facilities abroad in the 1970's, and the tendency for other countries to build national industries and shelter them from metal product imports. High tariff and non-tariff barriers were employed from 1950-1980 to protect European and Japanese copper industry expansions. Japan and European countries preferred reciprocal trade with less developed countries, even though U.S. mills were more efficient sources of brass mill products.

Changes in user technologies, because they affect regional demands, will also be factors in determining the pattern of world copper trade in the future. Leontief's study (1982) of copper production and consumption in the year 2000 (Exhibit 6) includes adjustments to reflect the expected increase of copper use in electrical-sector demands by 10 percent and in ordinance demands by 30 percent; but copper use is expected to decrease 10 percent in the construction, machinery, and transportation sectors (cf. below). The final effect of these changes on consumption of copper in a region depends on the differential rates of growth or decline maintained by the sectors using copper, and on the effects of changing trade patterns among countries. The net effect of all such changes can be computed as a coefficient giving the rate of copper consumption relative to the region's income. In the initial stages of development, a country's propensity to consume metals often increases, but after it reaches industrial maturity, this propensity often declines. Calculating propensities can be misleading when the metal in imported goods received is not counted in consumption, whereas the metal used in the region's manufacture of its export goods is counted in domestic consumption. For instance, the U.S. net propensity to consume copper is significantly understated by the fact that copper contained in the radiators of imported automobiles is excluded; in contrast, the German net propensity is overstated by the inclusion of exported automobile radiators as home metal consumption.

In addition to estimating future market shares, Exhibit 6 also estimates year-2000 world outputs and inter-regional trade patterns so these can be compared with those of 1950 (Exhibit 2) or 1974 (Exhibit 3). The results assume continued high growth in income per capita outside the U.S., but a slowing in world population increases. The forecasts also assume the maintenance of the current 50 percent recycling rate for copper in the U.S., as well as the continued decline of the U.S. share of industrial exports and the U.S. industrial consumption of raw materials. The consumption of other countries was adjusted on similarly gross bases. The world's copper consumption forecast is 23.9 million tons in the year 2000. This forecast compares only with the high U.S. Bureau of Mines projection of Exhibit 1A, which reaches 25.0 million tons in 2000, but maintains the 1974 distribution of trade in Exhibit 3. Given these "most favorable" assumptions, U.S. consumption is assumed to grow, at best, to 3.4 million tons and Canadian consumption to 0.4 million tons. The excess of North American production will be exported. These exports, largely from Canada, will follow present paths to European markets. Thus, the U.S. share of world output is expected to continue falling, hypothetically, from 25 percent to 15 percent, while world production and consumption will rise by 10 million tons. In Exhibit 6 projections, scrap use is maintained constant. Alternatively, if the U.S. scrap and imports are permitted to rise by 50 percent, all increased domestic consumption will be met from these sources, and no increase in the U.S. primary copper production will occur. Thus, the U.S. industry is not expected to contract in the future. In the second part of this paper, such predictions are shown to be overly pessimistic.

THE COSTS OF REGULATION

The relationships between rates of ore-grade depletion and technical change on one hand, and the externalities of production, such as safety and environmental problems on the other, are complex. An impressive increase in mining productivities occurred throughout the long period of output growth and ore-grade decline. The U.S. copper industry accomplished the increases largely by shifting to new, capital-intensive technologies, which greatly increased equipment and energy-use rates in mine operations and transportation. As the trend toward lower grades proceeded, it also became necessary to dispose of more waste. Ultimately, there was a shift to the massive open-pit

mining and extensive processing which characterize U.S. operations today and require the movement and refining of large quantities of material. At the extraction stage, these technical changes had serious impacts on the hazards of fire, explosion, and machinery-related accidents. Simultaneously, hazards to mill workers in the work environment increased proportionately with the expanded size, complexity, and sophistication of the machinery involved in processing. At the smelter and refinery stages, waste disposal and emission controls became special problems.

The mining industry's successes in reducing the numbers of accidents per man-hour and accident rates per ton have, nonetheless, been dramatic in more recent years. Success is due, in part, to the use of more productive techniques which removed labor from the mining and processing activities. Lower accident rates also resulted from the cooperation between management, organized labor, and government, which increased regulations and inspection pressures on the industry. Most safety improvements have come about without raising the real costs per ton of metal recovered so that mining costs continued to fall even after the implementation of the Mine Safety and Health Act of 1970 and its Administration (MSHA).

The application of the Occupational Safety and Health Act of 1977 has been directed largely to smelters and refineries, regulating hazardous air pollution and solid waste disposal. Its impact on copper costs has been more controversial. Preliminary estimates by Arthur D. Little, Inc., and others, on the control costs of SO_x and other trace elements in emissions, prepared for the Council on Environmental Quality in 1972 led many to predict relatively low costs for reaching compliance. Actual costs have been considerably higher. The copper industry estimates that cumulative compliance costs, mostly for sulfur control at smelters, have reached $1 billion. Annually these costs to date represent 3-4 cents per pound. As EPA regulations have become more stringent, expenditures have risen, but the real problem is obsolete smelters. The average age of 85 percent of the smelters in use is 60 years. Modification of existing furnaces to date has not brought them up to the 90 or 98 percent SO_x removal standards required by 1988. Expert metallurgists doubt seriously that the industry can meet the 90-percent standard with the smelters built in the early 1900's, and certainly not without significant further increases in costs (Dresher, 1978). Compliance may require a total cost of 10 cents per pound annually, according to Dorenfeld and others (1981). When the 98-percent standard is met, the total compliance cost may reach 18 cents per pound. Comparable costs are anticipated in National Science Foundation-sponsored studies (1977) and later studies of Arthur D. Little, Inc. (1978). In light of this obsolescence and of rising costs for the factors of production such as wages, therefore, the ability of the major U.S. firms to comply with pollution controls competitively has been questioned. Can new technology offset these costs?

The technology to control SO_x is fully developed and operative in other parts of the world. Davenport (1980) examines the advantages and disadvantages of the 28 successfully operating new furnaces built from 1970-1980. Of these, the most numerous are Flash furnace installations (16), followed by electric furnaces (5), Noranda reactors (4), and all other systems (3). These are listed in Exhibit 9. This equipment meets standards higher than those to be imposed by the EPA in 1988. Japan has pollution problems which are more severe than the U.S., due to the location of its industry close to population centers, and relies on highly varied ores produced abroad. Japan's success in controlling emissions at high standards without losing trade is partially due to high tariffs on primary metal and products. New smelters also receive offsets by selling recovered sulfur. However it is now clear that these new technologies bring significant savings in energy and higher efficiencies, and these savings have offset the incremental costs of environmental control. Whereas U.S. firms, by and large, have elected to buy time through modification of older reverberatory furnaces, the high energy consumption rates and difficulties of removing SO_x from the dilute gases have made this older retrofitted technology quite costly to operate. The rising cost of electric energy since 1973 has also slowed the further expansion of electric furnaces. Thus, the largest increase in future capacity is expected to go the the Flash furnace type in which SO_2 is collected efficiently at high strength as a commercial by-product by combusting particles in an oxygen-enriched atmosphere above the metal bath, or to the Noranda type which injects

EXHIBIT 9

COPPER SMELTING FACILITIES INSTALLED IN THE 1970's

Date	Location	Company	Hearth Size (m)
		FLASH FURNACES	
1970	Saganoseki, Japan	Nippon Mining Co. Ltd.	20 x 6-1/2
1971	Toyo, Japan	Sumitomo Metal Mining Co. Ltd.	20 x 7
1972	Ghatsila, India	Hindustan Copper Ltd.	17 x 6
1972	Mount Morgan, Queensland	Peko-Wallsend Metals Ltd	
1972	Tamano, Japan	Hibi Kyodo Seiren Co.	20 x 7
1972	Hamburg, Germany	Norddeutsche Affinerie	
1972	Hitachi, Japan	Nippon Mining Co.	18 x 7
1973	Samsun, Turkey	Karadeniz Bakir Isletmeleri, A.S.	
1973	Tennant Creek, Queensland	Peko-Wallsend Metals Ltd.	
1973	Saganoseki, Japan	Nippon Mining Co. Ltd.	20 x 7
1974	Khetri, India	Hindustan Copper Ltd.	17 x 6
1975	Huelva, Spain	Rio Tinto Patino S.A.	
1976	Hidalgo, New Mexico	Phelps Dodge Corporation	23 x 8
1977	Glogow, Poland	Kombinat Gorniczo-Hutniczy Miedzi, Lubin	
1980	Taihan, Korea	Onsan Copper Refinery Co. Ltd.	
1980	Salvador, Brazil	Caraiba Metals S.A.	
		ELECTRIC FURNACES	
1971	Mufulira, Zambia	Roan Consolidated Mines Ltd.	36000 KVA (dry concentrate)
1972	Copper Hill, Tennessee	Cities Service Co.	8000 KVA (calcine)
1974	Inspiration, Arizona	Inspiration Consolidated Copper Co.	51000 KVA (dry concentrate)
1976	Anaconda, Montana	The Anaconda Co.	36000 KVA (calcine)
1978	Falconbridge, Ontario	Falconbridge Nickel Mines Ltd	36000 KVA (two) (calcine)
		NORANDA PROCESS	
1973	Noranda, Quebec	Noranda Mines Ltd.	5m dia. x 21m long
1978	Garfield, Utah	Kennecott Copper Corp.	three 5m dia. x 21m long
		TBRC	
1978	Kamloops, B.C.	Afton Mines Ltd.	4 x dia. x 6-1/2 long
1978	Ronnskar, Sweden	Boliden Metall AB	30m³
		MITSUBISHI PROCESS	
1974	Naoshima, Japan	Mitsubishi Metal Corporation	7 x 10m smelting furnace
1979	Timmins, Ontario	Texasgulf Canada	11m diameter smelting furnace
		KIVCET PROCESS	
1973	Glubokoe, Kazakhstan	Irtysh Polymetal Combine	5 x 20m

Source: Davenport (1980), Copper Smelting to the Year 2000.

pure oxygen into the metal bath. The amount of sulfur and iron oxidized in the smelting is determined by how much pure oxygen is used. Much more oxidation per unit of extraneous energy is applied because of the energy released by the process. This "self-generating" or autogenous operation accounts for efficient reduction of fuel consumption. The results are lower variable costs than are possible with either rehabilitated or new reverberatory furnaces, systems which have been rendered obsolete by new developments.

The switch from reverberatory to autogenous processes, such as the Flash furnace, has been assisted by a number of important developments, in particular (1) U.S. innovations drastically reducing the cost of pure oxygen during the 1950's, (2) the large incentives to reduce energy consumption in smelting since the four-fold increase in real energy costs during the 1970's, and (3) the development of sophisticated, computerized controls permitting high quality output from the faster autogenous metallurgical processes.

Latin American and African countries have encumbered their nationalized copper industries with few smelter regulations. On the other hand, they are eager to extend their value added during production by expanding domestic smelting. Clearly, it will also be cheaper for them to build a new industry based on Flash or Noranda furnace technology than to replicate the older furnace technology.

Does the quality of U.S. reserves warrant the expenditures required to replace the older smelting technology or will it be cheaper for the industry to export the problems of pollution by importing metal? Ore-grade declines in the U.S. will not control U.S. reinvestment decisions. North America has a larger reserve base of ore than Africa, Asia, or Latin America. The U.S. can reach the levels of production forecast through 2000 without significant declines in ore grade. Labor differentials will not be compelling factors in the reinvestment decision either. Capital costs, therefore, along with the other adoption costs of the new technologies, will hold the key.

The capital costs of opening new mines, smelters, and refineries are $9,000 per ton of annual capacity. These costs are very high, whether the installations are built in developed or underdeveloped countries. Exhibit 10, which employs the costs of Sousa's capital estimates in current (1981) dollars of 73 cents per pound and assumes present variable costs of 60 cents, shows that $1.33 per pound of copper is required to open new mines outside the United States. The capital costs of expanding existing U.S. mines, in contrast, are only 43 cents per pound. The variable costs for new U.S. facilities are comparable to those abroad. Therefore, to increase U.S. capacity to 3.7 million tons would require U.S. prices of only $1.03 per pound.

This incremental .7 million tons can be obtained at a cost quite competitive with the incremental costs of expansions abroad. Indeed, although estimates differ, almost all experts see the necessity for much higher copper prices around the world when expansion resumes. Metal prices are expected to rise to at least $1.40 per pound (in 1982 dollars). Certainly, under such price conditions, the U.S. industry will also prosper.

EXHIBIT 10

COMPARATIVE COSTS OF U.S. EXPANSION AND NEW WORLD CAPACITY IN COPPER
(in 1982 constant dollars)

	CAPITAL COSTS				FULL COSTS[3]	
	United States[1]		Rest of World[2]		United States	Rest of World
	$/ton of capacity	¢/lb	$/ton of capacity	¢/lb	¢/lb	¢/lb
Mines	$4,000		$5,900			
Smelters	700		2,500			
Refinery	NA		600			
Total	$4,700	43¢	$9,000	73¢	$1.03	$1.33

[1] Assumes domestic demand requires expansion of existing capacities by .5 million tons in mines and .7 million tons in smelters; no increase in refinery capacity. Capital costs updated to 1982 by applying factor of 1.4 to Sousa's 1977 estimates.

[2] Assumes world demand requires expansion by new facilities by 3.0 million tons in mines, smelters and refineries.

[3] Assumes present variable costs of 60¢ per pound with negligible capital costs on old facilities.

Source: Sousa (1981), *The U.S. Copper Industry*, and author's estimates for expansion scenario and inflation adjustments.

FEDERAL MANAGEMENT OF STRATEGIC MINERAL LAND AND TAX POLICIES

Anglo-American land and mineral policies have traditionally been based on a very different philosophy from those of other countries. Historically, much of the resource wealth of the U.S. consisted of public land, which was freely distributed among private-sector developers. In contrast, the other major copper-producing countries were developed under the Napoleonic code or earlier concepts in which natural resources belonged to the state. The nationalization of foreign copper concessions by host countries in Africa or Latin America have a precedent in such law. Similarly, there is long precedent in other major consuming countries, such as Japan and in Europe, to form state trading monopsonies for the purchase of materials and state monopolies for the development of sources. This practice has led to well-defined rents and high taxes on copper. The U.S. historically avoided the development of producer or consumer cartels. By giving away federal resources so energetically that excess demand and high prices were the exception rather than the rule, the U.S. neglected the collection of rents and royalties and emphasized the benefits of competition and cheap materials procurement. When problems in conservation and environmental control developed and became aggravated by excess supply, they were relegated to Congress. It is no accident that conservation became a significant political issue early in the 19th century as commodity prices declined. However, since 1960, environmental control acts of Congress have internalized most of these external costs and may have raised them above the level of benefits to consumers. Withdrawals of public land were the result of the Alaska Native Claims Settlement Act of 1971, the Alaska National Interest Lands Conservation Act of 1980, and the Federal Land Policy and Management Act of 1976. Together, these legislative acts have discouraged aggressive mineral exploration and development. At the same time, concerns over strategic material resources have led to some subsidies for domestic mineral industry expansion. Clearly, the decision in the 1950's to inventory copper in a national strategic stockpile encouraged the opening of new copper mines. Thus, recent legislative history has had mixed impacts on the copper industry.

For decades the concentration of U.S. firms mining and smelting copper has been diluted due to vigorous antitrust actions which discouraged domestic growth of the major companies and continually constrained their operations. Later, the strategic stockpile became a federal instrument to control inflation and stabilize prices, and growth was further discouraged. U.S. policies can be shown to have discouraged the expansion of U.S. firms abroad, in contrast to the policies of other developed nations. At best, therefore, U.S. government policies have been both confused and conflicting. The Department of Interior and other branches of federal administration have been urged by economists to make timely and much needed reforms. Current review of nonfuel minerals policy is especially welcomed by industry, in light of the above.

Some observers argue that federal environmental policies compel a basic choice between domestic or foreign sources of copper; however, these arguments are not convincing. The projected growth of U.S. firms through the year 2000 (if growth does indeed occur) is supported by ample competitive U.S. copper reserves in private hands. These reserves are almost all cheaper to mine than the proved, indicated, or estimated reserves on federal lands. Finally, the state and federal taxation of copper is lower than that of other metal resource industries in the U.S. or abroad. Many producing countries have taxed all gains by nationalizing copper production. For profitable U.S. companies, a depletion allowance of 15 percent of value of copper refined shelters revenues from income taxes. Finally, tax credits are available for capital improvements.

While this analysis fails to confirm significant U.S. disadvantages on the supply side and supports the ability of domestic brass and mill-product producers to compete in the world markets when world demands resume their growth, it does not necessarily assure that U.S. firms will prosper or survive in the future. Concerns arise on the demand side because technical change and substitution may continue to erode world markets and because other countries, which export commodities to the U.S., refuse to permit U.S. firms to trade freely in their own markets. The ability of the U.S. industry to survive, therefore, depends on more than low-cost production. It also depends very much on access to growing consumption in the markets outside the United States. These problems and their solutions on the demand side will be described in the concluding part of this article.

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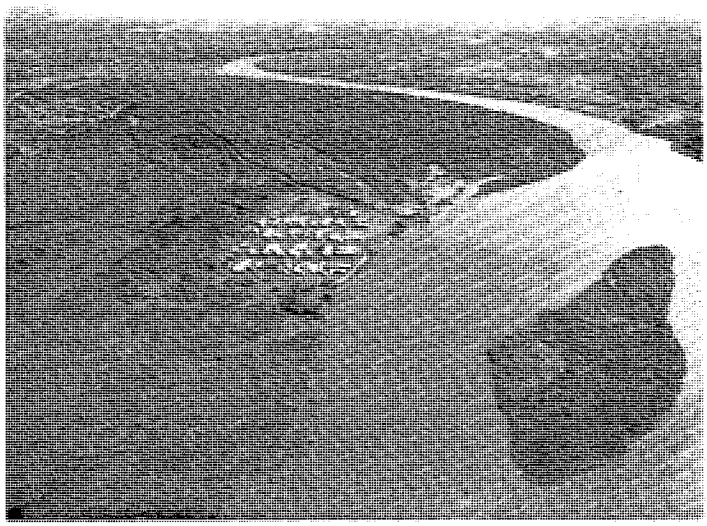
EXPANDED BLM MINERALS PROGRAM

By Secretarial Order, dated December 3, 1982, the Bureau of Land Management (BLM) assumed all onshore minerals management functions including oil and gas, geothermal, and solid leasable minerals on both Federal and Indian lands. These functions, which were formerly the responsibility of the U.S. Geological Survey (USGS), include mineral resource evaluations, fair-market-value determinations, approval or rejection of drilling permits and mining or production plans, and on-site inspection and enforcement of mineral-lease operations. These expanded BLM mineral responsibilities will be in addition to the historical BLM mineral role with respect to mining claims, saleable minerals, and issuance of leases. The BLM will also now provide assistance to the Bureau of Indian Affairs in the supervision of mineral operations on Indian lands.

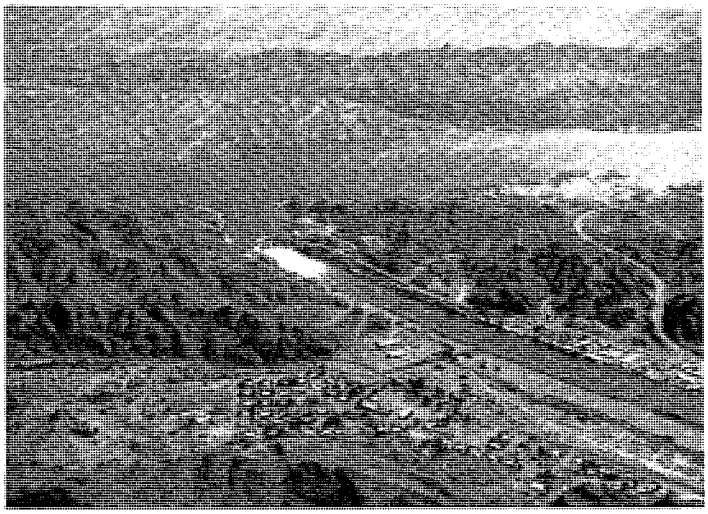
The consolidation of onshore minerals management activities should provide greater emphasis on opportunities for energy and mineral development on Federal and Indian lands, strengthen mineral resource expertise in the BLM, streamline mineral leasing procedures, and enhance mineral considerations in multiple resource management and land-use decisions. The BLM Director has also set forth a minerals policy that encourages the development of mineral resources.

The BLM Arizona State Office has established a position of Deputy State Director, Mineral Resources, and an expanded staff to provide greater focus to the Federal and Indian land minerals program in Arizona. Mr. Ray A. Brady, who was selected as the Deputy State Director, is a graduate of the University of Arizona (1970) with a degree in Geology and is returning to his home state of Arizona. His professional experience includes work with hardrock minerals, oil shale, coal, uranium, and potash in Arizona, Colorado, and New Mexico. Mr. Brady was Deputy Manager of Mining, in the Albuquerque, New Mexico office of the USGS prior to his reassignment to the BLM Arizona State Office in Phoenix.

Colorado River in Flood Stage



View is north across the southern Cibola Valley, south of Blythe. Flooded trailer court is Gilmore's Camp, located north of Walker Lake and across the river from Cibola Lake. Barely visible in the upper left is another partially flooded development, Walter's Camp, also known as Paymaster Landing. The river here divides Imperial County, California (left) and Yuma County, Arizona (right). Photo by Peter L. Kresan.

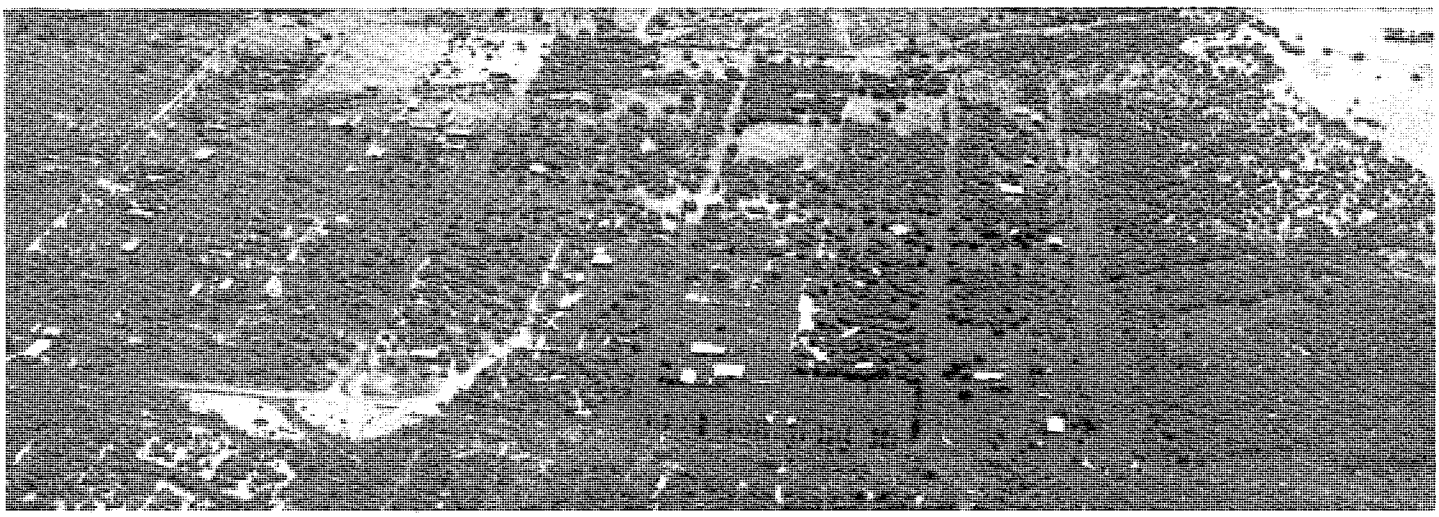


Parker Dam and the Bill Williams River Embayment of Lake Havasu is shown in this view northeast. Aubrey Hills are above the lake. Arizona Highway 95 curves through hills above the Parker Strip on the far right. Photo by Peter L. Kresan.

View is east along the Colorado River, confined by levees, just east of Yuma. Highway I-8 is seen in the lower right and the Gila River joins the Colorado where the main channel bends to the north (to the left). Photo by Peter L. Kresan.

Photographs were taken on the morning of July 8, 1983.

Flooding of buildings is shown in this view southeast across Topoc Marsh. The development is just north of Goose Lake on the Fort Mojave Indian Reservation, Arizona. Needles, California is due east across the main channel of the Colorado River. Photo by Peter L. Kresan.



LEST WE FORGET (Of Oil Gluts and Gas Bubbles, and Cabbages and Kings)

A Guest Editorial
by
Howard Bucknell*

Following a year or so of rhetoric in the national press concerning the demise of the energy crisis, we were then treated to an impassioned analysis as to the imminent collapse of OPEC (Organization of Petroleum Exporting Countries) or some dramatic restructuring of world oil pricing procedures. The short-term prospects of such events seemed fairly evident: lower oil prices. However, the longer-term prospects appeared more complex. The purpose of this short essay is to point out, lest we forget, that these longer-term prospects should be kept in mind. They include the alternatives of prosperity and poverty, and peace and war — probably within the present decade.

Today an "oil glut" certainly continues to exist. It is the product of gross overpricing, and resultant unemployment and recession, the beginnings of conservation efforts, and some use of alternative fuels (coal). Despite brightening conditions in our own country, more than 25 million skilled workers are still unemployed in the 24 OECD (Organization for Economic Cooperation and Development) countries. People without jobs don't drive to work in big or small cars. Gasoline is "saved". Closed factories are marvelously energy efficient. Shutdown assembly lines do wonders for the energy budget. Thus depressed economic conditions are one answer to the energy crisis — which some now claim never occurred.

Substantial economic recovery cannot occur in the OECD (or the United States itself) without a concomitant increase in energy use — particularly of oil. Thus, a further significant drop in the price of oil, say $15 per barrel, would undoubtedly assist in economic recovery. A significant drop in the price of oil would also see the almost complete curtailment of drilling activity in this country (drilling starts are significantly down already, with an attendant slide toward greater foreign dependence), the cessation of synthetic fuel development (note the current curtailment of oil shale projects), and the complete abandonment of both the Canadian tar-sand venture and the development of the Venezuelan heavy-oil deposits. A drastic lowering of oil prices would force the disruption of Mexican oil production and the cessation of production from the North Sea oil fields. Venezuela, Mexico, and Nigeria would probably face economic collapse while dissolving simultaneously into political chaos. Ultimately a similar fate could await Great Britain and other friendly countries. To reckon that the United States could proceed unscathed amidst such chaos is to be extremely naive.

We should consider the impact on the average American. After all, gasoline prices, heating bills, and electric bills would go down. Money would be usefully released into the private and corporate spheres. The main impact on the average American, however, would come *after* the price drop had been achieved.

Those countries able to produce and distribute oil profitably at the lower price would have eliminated all sources of competition. As the oil-consuming world benefited from the price drop, the surviving oil-producing counties would control the market. These countries, by and large, rim the Persian Gulf and comprise the Organization of Arab Petroleum Exporting nations (OAPEC) and the so-called Gulf Corporation Council. These nations, controlling one-third of the world's proven oil reserves and led by Saudi Arabia, have long dominated OPEC. They expend on the average $2 to lift a barrel of oil from the ground. By comparison, North Sea oil is produced at a cost of about $9 per barrel.

At the present time the United States produces about 8.7 mbpd (million barrels per day) of oil (plus 1.5 mbpd of natural gas liquids) and imports about 5 million barrels each day to meet basic needs. In 1973 the U.S. imported about 6 mbpd, approximately 12 percent of which was from Arab sources. Of the 5 mbpd *currently* imported by the U.S. in a still austere economy, 41 percent comes from Arab sources. In 1974, when the Arab producers imposed an oil embargo shutting off less than a million barrels per day, about 500,000 Americans immediately lost their jobs. But those were very prosperous times. Today, with about 9 million Americans already (still) out of work, a similar embargo would deprive us of over 2 million barrels per day — or about 15% of our *total* (reduced) oil consumption. Nor has our Strategic Reserve been given much attention. Sadly enough, after years of talk, legislation, and political propaganda, our oil vulnerability and our dependence on Persian Gulf supply has become greater, not less.

Yet our vulnerability and dependency pales into insignificance when compared to that of Europe. Of the 10 million barrels of oil imported daily into Western Europe, fully 60 percent comes from the Persian Gulf. In spite of the output of the North Sea fields and imports of oil and gas from the Soviet Union, it is unlikely that Western Europe, recession or no, could survive in its present industrial, social, or political likeness if denied Persian Gulf oil.

Control of Persian Gulf oil then implies in every way *de facto* control of Europe. The movement of the Soviet Union toward the Gulf is understandable in this context alone. However, it can be additionally argued that the Soviet Union will one day require foreign oil to meet its own needs. In the same context, it is also understandable that the United States regards the Persian Gulf as an area of extraordinary strategic importance. The ability of the U.S. to safeguard this precious area is, however, limited.

The European nations whose welfare is so individually and collectively affected by Persian Gulf oil understand full well that no war of major proportions can be fought in the Middle East without interrupting the flow of oil to Europe. Regardless of who is to be the victor or the vanquished in such a contest, Europe can only be the loser. Therefore Europe, predictably, would not support the United States in a war against Soviet or Soviet-sponsored encroachments in the Middle East unless the United States were in a position of being able to replace the lost Persian Gulf oil in the fashion of the Suez Crisis of the 1950s. To underscore this point one must also remember that the Soviet Union is already a substantial supplier of oil and gas to Western Europe and that growing bonds of trade are being forged between these entities.

The only hope of increasing Western Hemispheric oil supplies to the point where they could substantially reduce

European dependence on Persian Gulf sources would be to fully develop our synthetic fuel resources, the Canadian tar sands, and the Orinoco River Heavy Oil Belt in Venezuela. In the face of any seeming OPEC breakup and a further sharp drop in oil prices, it is clear that these steps will not be taken until too late.

Thus further drastic drops in oil prices which many hope for, while promising short-term relief to our economy, could ultimately lead us into a quagmire where our neighbors are beggared, many of our great banks are broken, and breadlines are formed. In reaction to all this we could find ourselves in a war which would maim our children and destroy our friends, but not solve our problem. Lest we forget—the energy crisis has not yet been overcome.

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*Howard Bucknell, a 1944 graduate of the U.S. Naval Academy, retired from the U.S. Navy as Captain, received a Ph.D. in Political Science from the University of Georgia, and taught at The Ohio State University, where he directed the Energy and National Security Project. Dr. Bucknell formed John Addison Cobb Associates, a consortium of energy analysts, in 1980.

SO WHAT'S THE WORTH OF A GEOLOGIC REPORT By Arthur A. Socolow

Recently a highly dedicated watchdog of space and dollars suggested we dispose of our stock of published geologic reports because many of them are more than two years old. People who publish are supposed to know that it's all over for a book after a year and a half. I tried to explain that while Pennsylvania has undergone numerous geologic upheavals over the millions of years, our geological reports would still be valid and useful after several decades. Our efficiency experts didn't give up. How come, said he, most of the geologic reports we have issued only sell 20 to 50 copies a year - how important can they be?

Good question: How important is a geologic report? How much is the report worth if it enables the highway department to pick a route that saves millions of dollars in construction costs? What's the value if the report identifies the location of mineral deposits needed to provide lime for the farmers, clay for the brickmakers, or coal for the steel industry? To justify its existence, how many copies of a geologic map must be sold which shows the location of geologic faults hazardous to nuclear power plants, and the location of sinkholes hazardous to schools and dams? How do you assess the value of a geologic report which identifies the location of groundwater needed to locate a new glass factory employing hundreds, or a sprawling, new multi-million dollar bottling operation? If our reports lead to natural gas occurrences that heat our homes, and dam sites that keep them from being flooded, must we sell as many copies as *Gone With the Wind* to justify their existence? Among those who tunneled the Turnpike, designed routes 80 and 81, engineered the renewal of Philadelphia, developed water wells for thirsty Lehigh, Bucks, and Chester Counties, rehabilitated the stripped lands of Western Pennsylvania, none of those eager users of our geologic reports were less thankful because the reports were done 10 years ago and the sale of the publications did not make the *Times'* best seller list.

To those who concern themselves over cost benefit ratios, turnover, and timeliness, we who issue geologic reports say: Rest easy. Be assured the value of the report is not measured by its $4.75 price (plus tax); nor does its 1962 date relegate it to the uselessness of a vintage phone book; nor does its annual sale of 47 copies measure real need. Whether they provide mineral raw materials for our industries, locate the waters needed for our survival, identify the geologic hazards that can ruin us, or assist the road builders, farmers, and recreation planners, our geologic reports measure up well to the test of time and value.

Editor's note: We thank Mr. Socolow, State Geologist of Pennsylvania, for giving us permission to reprint this article, which originally appeared in Pennsylvania Geology, v. 13, no. 5, October 1982.

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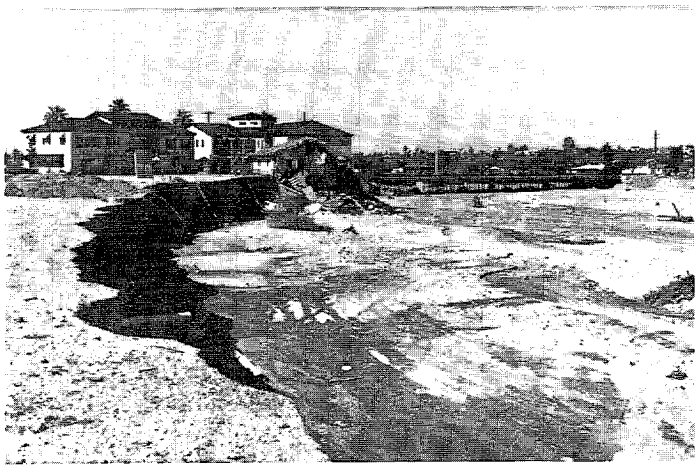
RIVERS IN THE DESERT — OCTOBER 1983



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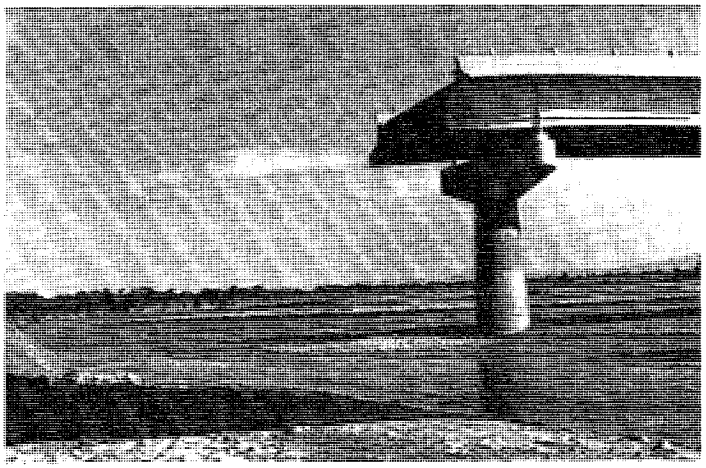

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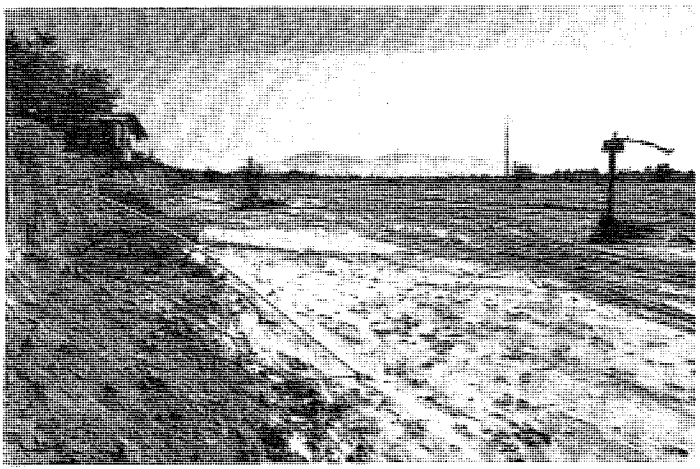

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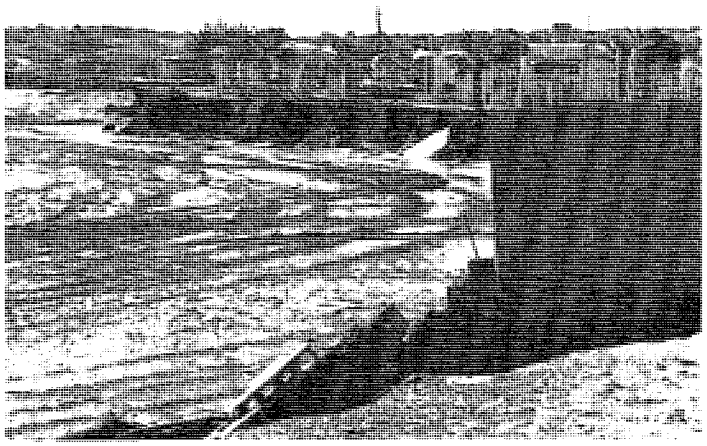

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A. Rillito river near 1st Avenue looking downstream. Post in river marks former bank. Erosion removed about five acres and undercut building. (Tucson)

B. Santa Cruz river at I-19 bridge crossing south of Tucson. Bank erosion out of picture to left destabilized bridge support allowing a span to collapse.

C. Rillito river near north Columbus looking upstream. Well casing left high and "dry" by more than one hundred feet of bank erosion. (Tucson)

D. Pantano Wash looking upstream. Bank erosion encroached upon trailer park washing away some and threatening others. (Tucson)

Watch for further developments of this and related subjects in a future issue of *Fieldnotes*.

Fieldnotes

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POTENTIAL GEOTHERMAL RESOURCES IN ARIZONA

*by Claudia Stone**

GEOTHERMAL ASSESSMENT PROGRAM AND ACCOMPLISHMENTS

A five-year program to locate and evaluate the potential geothermal energy resources in Arizona was brought to completion in 1982 and results were summarized in a comprehensive final report. The U.S. Department of Energy (DOE), Division of Geothermal Energy, was the principal funding agency although additional funds were received from the U.S. Department of Interior, Bureau of Reclamation, during two of the years the program was in existence. All funding for the program was awarded to the University of Arizona, Bureau of Geology and Mineral Technology.

Several publications and numerous unpublished technical reports and maps were produced by program personnel. Hahman, Stone, and Witcher (1978) compiled the preliminary geothermal indicators known to that time on a 1:1,000,000-scale map, "Geothermal Energy Resources of Arizona". Four years later this map was updated to include information generated during the intervening years. This 1:500,000-scale map, "Geothermal Resources of Arizona" (Witcher, Stone, and Hahman, 1982), depicts identified and suspected geothermal occurrences in Arizona. Figure 1. Compiled and interpreted

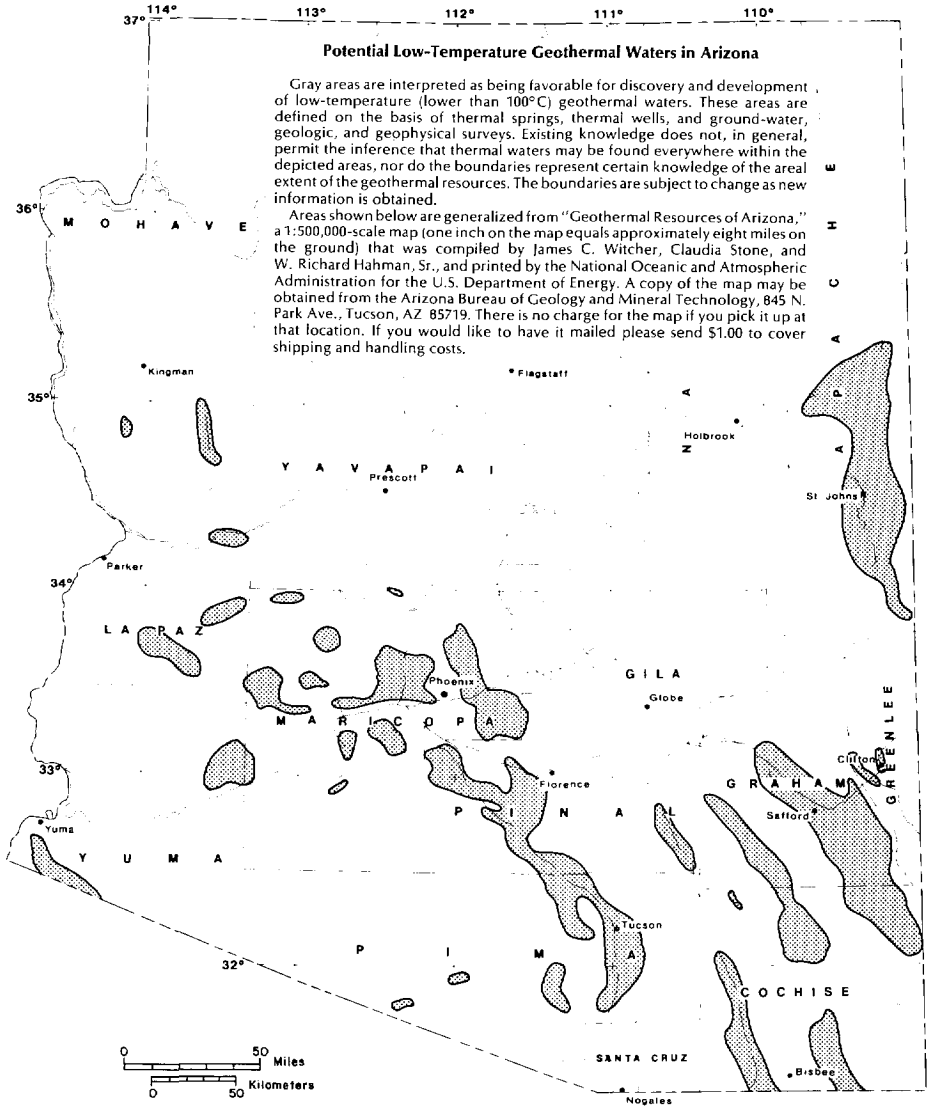

Figure 1. Potential low-temperature geothermal waters in Arizona.

*Claudia Stone worked on the Bureau's geothermal program from start to finish. She began in 1977, shortly after receiving a Master's degree in geology and geophysics from the University of Hawaii, and was promoted to project manager in 1981 with the responsibility for bringing the project to completion. Ms. Stone is now a consulting geologist and principal in Stone and Associates in Sacramento, California.

by the authors, the map was printed by the National Oceanic and Atmospheric Administration for the DOE as part of their State-Coupled Program. A bibliography of geothermal and related research in Arizona was compiled by Calvo (1982) and published by the Arizona Bureau of Geology and Mineral Technology. The final report to the DOE (Stone and Witcher, 1982) summarizes the nature of potential geothermal resources in Arizona, the thermal regime of the state, the principal geothermal anomalies studied, and exploration methods used. All reports, maps, and area assessments have been placed in the Bureau's open-file series and are available for examination or purchase. A complete list of maps and reports in the open-file series was included in the Summer 1983 issue of *Fieldnotes*, the Bureau's newsletter.

Reconnaissance exploration during the geothermal program was used to identify more than 15 areas in Arizona where low- to moderate-temperature geothermal fluids (to about 140°C) are known or believed to occur at depths shallow enough to make them useful as alternate sources of energy. Not all parts of the state were assessed with equal intensity, however. For reasons of accessibility, limited manpower, and proximity to major population centers, exploration generally was concentrated in southeastern Arizona. Thus, the largest number of potential geothermal resource areas were identified there. Other geothermal anomalies may exist in parts of Arizona that were not studied during this program.

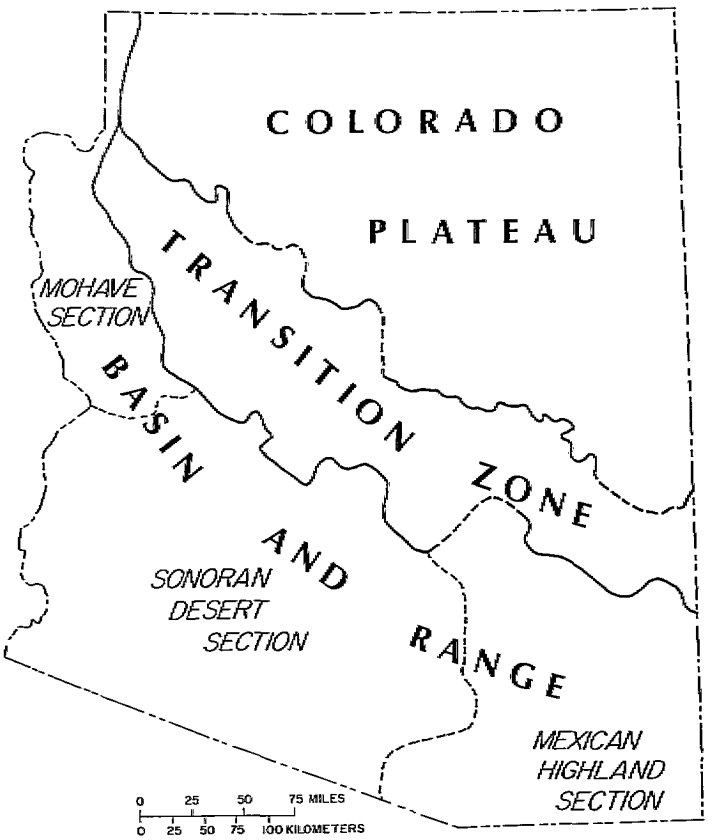

Figure 2. Physiographic provinces and subprovinces of Arizona.

POTENTIAL GEOTHERMAL RESOURCES IN SOUTHERN ARIZONA

Southern Arizona is in the Basin and Range province (Figure 2), where deep sediment-filled basins are separated by generally high, broad mountain ranges. Because temperatures normally increase with depth in the earth, temperatures in the deeper basins are high and deeply circulating ground water becomes quite warm. A basin 1500 m deep could produce water with temperatures as high as 70°C. A 4000 m basin could contain 140°C water.

Many basins in southern Arizona have different geologic conditions, a situation that leads to a variety of cold, warm, and hot water occurrences. In some basins, water movement may be hindered by impermeable clay layers or structural barriers to circulation, and the water in these basins will remain cool. Some basins are not deep enough to have high temperatures so the ground water remains cool even if there is unrestricted circulation. In other basins, ground water lies at great enough depths to be naturally heated without a hydrothermal convection system. Sufficiently deep wells will encounter these fluids. If it is under artesian pressure, the water will rise in the well bore and may flow at the surface. Numerous such thermal artesian wells are present in the San Simon Valley, for example. In still other basins, geologic conditions enable a natural hydrothermal convection system to become established. The circulating hot water rises toward the surface, usually along a fault plane; if it leaks out, thermal springs develop.

Witcher (1981b) identified 20 hot springs and 25 warm springs in Arizona. The hottest springs are in Greenlee County, southeastern Arizona. Gillard Hot Springs discharges 84°C water and Clifton Hot Springs, 70°C water. Reconnaissance studies in this region (Witcher, 1981a; Witcher and Stone, 1980, 1981), however, suggest that temperatures at depth may be as high as 160°C at Clifton and 140°C at Gillard. Ross and Farrar (1980) showed that hot springs in Verde Valley, which have discharge temperatures as warm as 39°C, may have reservoir temperatures greater than 100°C. In a detailed study of Clifton Hot Springs, Witcher and Stone (1980) concluded that two processes prevent the hot reservoir fluids from reaching the surface with their initial temperature. As the fluids rise toward the surface (1) the thermal water mixes with cold, shallow ground water, and (2) the hot water loses heat to the enclosing country rock. One or both of these processes probably operate at Gillard Hot Springs, as well as at other hot springs in Arizona and elsewhere. Thus, the temperature of a thermal spring may or may not represent the maximum water temperature at depth.

Other areas in southeastern Arizona that have geothermal anomalies, some of which are associated with warm artesian wells rather than hot springs, are listed in Table 1. The thermal water in most of these reservoirs is contained in coarse-grained sands and gravels confined beneath impermeable beds of clay and silt.

Low- to moderate-temperature geothermal waters are present in numerous other parts of southern Arizona (Witcher, Stone, and Hahman, 1982). Witcher (1982) concluded that geothermal fluids beneath Tucson occur in a deep aquifer (greater than 500 m depth) that is apparently confined and hydrologically separate from the shallow aquifers (less than 200 m depth) that provide drinking water for the Tucson metropolitan area. The shallow

TABLE 1. SELECTED GEOTHERMAL AREAS IN SOUTHEASTERN ARIZONA

Area Name	Maximum Measured Temperature (Degrees C)	Estimated Reservoir Temperature (Degrees C)
Willcox	54	60 - 65
Buena Vista	49	60 - 70
Cactus Flat-Artesia	46	65 - 70
San Simon	43	35 - 45
Bowie	37	90 - 100

aquifers produce 30° to 33°C water; the geothermal fluids have temperatures between 52° and 57°C and their chemistry is distinctive.

Temperature measurements in domestic-water wells belonging to th city of Scottsdale show a zone of lateral flow of 40° to 50°C water at 335 m depth beneath the city. Stone (1981) estimated that fluids with temperatures to about 60°C exist to depths of about 900 m, and that significantly hotter waters may exist at depths of 1,800 m and greater. Pumped wells in Mesa produce 37° to 54°C water from depths of 90 to 300 m.

In south-central Arizona, geothermal fluids rise through fractured bedrock at the intersection of two fault zones at Papago Farms on the Papago Indian Reservation. Fluids pumped from about 240 m depth have temperatures as high as 51°C, but deeper reservoir temperatures may be as high as 140°C (Stone, 1980a). Other geothermal areas in south-central and southwestern Arizona, together with their estimated reservoir temperatures, are listed in Table 2.

TABLE 2. SELECTED GEOTHERMAL AREAS IN SOUTH-CENTRAL AND SOUTHWESTERN ARIZONA

Area Name	Maximum Measured Temperature (Degrees C)	Estimated Reservoir Temperature (Degrees C)
Castle Hot Springs	46	85 - 100
Coolidge	72	105 - 110
Tonopah	51	65 - 70
Avra Valley	53	50 -55
San Manuel	42	less than 60
Northern Hassayampa	53	70 - 75
Southern Palomas	49	90 - 95
Yuma	38	greater than 100

POTENTIAL GEOTHERMAL RESOURCES IN NORTHERN ARIZONA

That portion of northwestern Arizona within the Basin and Range province (Figure 2) appears on the map, "Geothermal Resources of Arizona" (Witcher, Stone, and Hahman, 1982), to have little resource potential. However, this conclusion probably is not correct. Most likely the area appears barren because it has received only limited attention.

Thermal springs in northwestern Arizona have discharge temperatures as high as 58°C and geothermometer temperatures, which suggest reservoir temperatures at depth, as high as 120°C. Goff (1979) concluded that the area between Kingman and Williams has several small, isolated geothermal reservoirs with fluids that may be as hot as 115°C. West and Laughlin (1979) showed that the Aquarius Mountain area has many of the anomalous conditions associated with thermal enhancement of the crust. They concluded that although the area does not have an insulating blanket of sedimentary rocks, "the prospect appears worthy of additional investigation. . . ." Shearer and Reiter (1981) proposed that high heat-flow values on the west side of the Big Sandy Valley are due to shallow hydrothermal convection systems. Industry showed some interest in the area during the late 1970s, but results of their investigations are unknown.

The north-central and northeastern portions of Arizona are in the Colorado Plateau province (Figure 2), an elevated area of comparatively flat-lying, relatively undeformed sedimentary rocks that are slightly tilted to the northeast. Preliminary information suggests that three areas in this region may have geothermal energy potential: the San Francisco volcanic field near Flagstaff, the White Mountain volcanic field near Springerville, and an area southwest of Sanders.

Thermal water has not yet been identified in the Flagstaff region, but Stone and Witcher (1982) proposed that "a significant geothermal resource may exist at depth (beneath the younger part of the field) judging from the number, size, and youth of silicic volcanic centers". Extensive investigations have been conducted in this region by the U.S. Geological Survey, but their results have not yet been published. Stone (1980b) showed that in the White Mountain volcanic field a corridor from St. Johns to Alpine has low- to moderate-temperature geothermal potential. The area has anomalously high heat-flow values and geothermometer temperatures (to 110°C). The Springerville-Alpine geothermal anomaly is the only area in Arizona known to be currently receiving attention from a private development company. Phillips Petroleum Company has conducted limited geothermal exploration in both the San Francisco and White Mountain areas, but results of their investigations are unknown. About 15 km southwest of Sanders, nine thermal wells and two anomalously high heat-flow values cluster in an area less than 100 km^2. The source of this anomalous heat is not well understood because the area has not been studied.

CURRENT GEOTHERMAL PROJECTS IN THE WESTERN UNITED STATES

Geothermal energy can be used in two principal ways. The first is generation of electric power by steam or high-temperature fluids, generally above 180°C. Electricity has been produced from steam at the Geysers in northern California since 1960, with present output exceeding 1,000 megawatts. The second and more common way is direct utilization in which the far more abundant low- to moderate-temperature fluids, such as exist in Arizona, are used directly to supply low-grade heat without the intermediate stage of power production. Many direct-use applications and their required temperatures were listed by Anderson and Lund (1980). District heating systems are in operation in Boise, Idaho; Jemez Springs, New Mexico; and Klamath Falls, Oregon. The Campus Heating Project at New Mexico State University, Las Cruces, achieved a gross cost avoidance of $250,757 between February 1982 and March 1983 by

using geothermal energy to heat several buildings on campus.

POSSIBLE USES OF GEOTHERMAL ENERGY IN ARIZONA

Numerous opportunities exist in Arizona to use the abundant low- to moderate-temperature geothermal fluids that have been identified. The possibility of implementing geothermal space conditioning has been studied for Williams Air Force Base, Chandler (cooling), Swift Trails Federal Prison Camp, Safford (heating), and a hotel complex in Tucson (heating). Space conditioning, especially heating, which requires lower fluid temperatures than cooling, could probably be established in a number of Arizona towns. White and Goldstone (1982) showed that recovery of copper in a dump-leaching operation increases from about 55 percent using 25°C water to 70 percent using 40°C water. Studies of cyaniding show that the rate of dissolution of gold in 25 percent KCN at 20°C increases about 120 percent when the temperature is increased to 50°C. Other applications include preheating boiler water for conventional power plants, controlled-environment agriculture (greenhouses and nurseries), process heat for slaughterhouses, fish farming, grain and vegetable dehydration, and soil warming for mushroom growing and earthworm farms. The actual list of potential geothermal applications is as long as one's imagination. Wherever low-grade heat is needed in Arizona, the possibility of using this alternate energy should be examined. Development awaits the entrepreneur.

CONCLUSIONS

Geothermal fluids having low to moderate temperatures are abundant in Arizona. This alternate source of energy is not free, and without vigilance, development could be impeded by legislative and institutional constraints. However, the benefits to be derived from development of geothermal resources in Arizona today are major. Such benefits include an improved quality of life because of the low environmental impact made by low-temperature geothermal projects, energy independence, and relief from escalating fossil-fuel prices, which are certain to rise in the future. Other potential benefits require only a little imagination.

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ANNOUNCEMENT: Bulletin 194, "Metallic Mineral Districts and Production in Arizona," has been released by the Arizona Bureau of Geology and Mineral Technology. The bulletin consists of a map (1:1,000,000 scale) that shows metallic mineral districts, brief text, and a table that indicates metal types and amounts produced from each district. Mineral districts were defined by geological criteria and classified by age of mineralization, if known, style of mineralization, and metallic minerals produced or present.

Bulletin 194 may be purchased for $6.50 plus $2.00 for handling and shipping, if it is to be mailed. The map may be purchased separately for $2.00 plus $1.50 for shipping and handling, if it is to be mailed. Address orders to the Arizona Bureau of Geology and Mineral Technology, 845 N. Park Avenue, Tucson, AZ 85719.

MINERAL-RESOURCE POTENTIAL OF WILDERNESS AREAS IS ASSESSED

A report that summarizes assessments of the mineral-resource potential of about 45 million acres of wilderness and potential wilderness tracts on U.S. Forest Service and Department of the Interior lands has been published by the U.S. Geological Survey (USGS). The two-volume report, which represents 20 years of study by scientists of the USGS and the U.S. Bureau of Mines (USBM), contains summaries of the mineral- and energy-resource potential of about 800 wilderness and proposed wilderness tracts, almost all within national forests.

The report shows that of the 332 tracts studied, 220 contain areas considered to be favorable for the occurrence of one or more kinds of mineral or energy resources. The summaries are organized by states and contain sketch maps of each wilderness study area showing which parts have mineral potential. The Arizona chapter, in volume one, is comprised of assessments of 25 tracts. A number of tracts have not yet been studied by the USGS or the USBM.

Each area assessed has been the subject of field studies, including geologic, geochemical, and geophysical surveys and investigations of mines, mineral prospects, and mineralized areas. When available, data obtained from private-sector exploration were incorporated in the assessments. Each of the summaries in the report is based on more-detailed reports released during the past 20 years, or to be released soon.

Mineral-resource potential, as discussed in the summaries, is defined as a measure of the likelihood of the occurrence of valuable metallic, nonmetallic, or energy minerals in a specific area. This potential is determined by analyses of the known resources and the characteristics of the geology of each area and comparison to areas with known mineral deposits.

Dr. Dallas Peck, director of the USGS, said the resource assessments by the two Interior agencies are aimed at providing impartial information on the resource potential of each study area that can be used by Congress and government officials in deciding how the area is to be used.

The Wilderness Act of 1964 and subsequent legislation required the agencies to assess the mineral potential of all lands within the National Wilderness Preservation System and all lands being considered for inclusion in the system. Since the program began in 1964, the amount of land to be studied has tripled from the original 14.8 million acres to 45 million acres.

The report, titled "Wilderness Mineral Potential — Assessment of Mineral-Resource Potential in the U.S. Forest Service Lands Studied 1964-1984", was published as USGS Professional Paper 1300. The report and the individual summaries were compiled and edited by Sherman P. Marsh and Susan J. Kropschot of the USGS and Robert G. Dickinson of the USBM, all in Denver, CO.

The report can be purchased from the Branch of Distribution, U.S. Geological Survey, 604 South Pickett St., Alexandria, VA, at a cost of $32 for each two-volume copy. Orders must include the full name and the identification number (PP 1300) of the report along with checks or money orders payable to the U.S. Department of the Interior-USGS.

Copies of the report are also available for inspection only at USGS libraries and at various other public and university libraries across the nation.

BUREAU GEOLOGISTS LEAD FIELD TRIP TO EXAMINE MAJOR FAULTS AND ASSOCIATED MINERALIZATION IN WEST-CENTRAL ARIZONA

A major responsibility of the Bureau is to conduct research and provide information about the geology and mineral resources of the State. Bureau geologists often use geologic field trips to communicate results of new research to geologists from industry, governmental agencies, and academic institutions. In November, Bureau geologists Robert Scarborough, Stephen Reynolds, and Jon Spencer led the Arizona Geological Society Fall Field Trip into the Plomosa and Granite Wash Mountains of west-central Arizona (Figure 1). The trip was attended by approximately 140 persons, most of whom were mineral exploration geologists interested in the relationships between mineralization and gently dipping faults. Others in attendance included geologists from the U.S. Geological Survey, the Bureau of Land Management, and other Arizona universities and colleges. The focus of the trip was to examine major thrust and detachment faults, some of which were unrecognized prior to geologic mapping by Bureau geologists. Parts of the Field Trip Guide are available as the following Bureau Open-File Reports:

Scarborough, R., and Meader, N., 1983, Reconnaissance geology of the northern Plomosa Mountains: Open-File Report 83-24 (36 p.).

Reynolds, S.J., Spencer, J.E., and Richard, S.M., 1983, A field guide to the northwestern Granite Wash Mountains, west-central Arizona: Open-File Report 83-23 (11 p.).

Please refer to pages 11 and 12 of this issue for more information on how to obtain Bureau Open-File Reports.

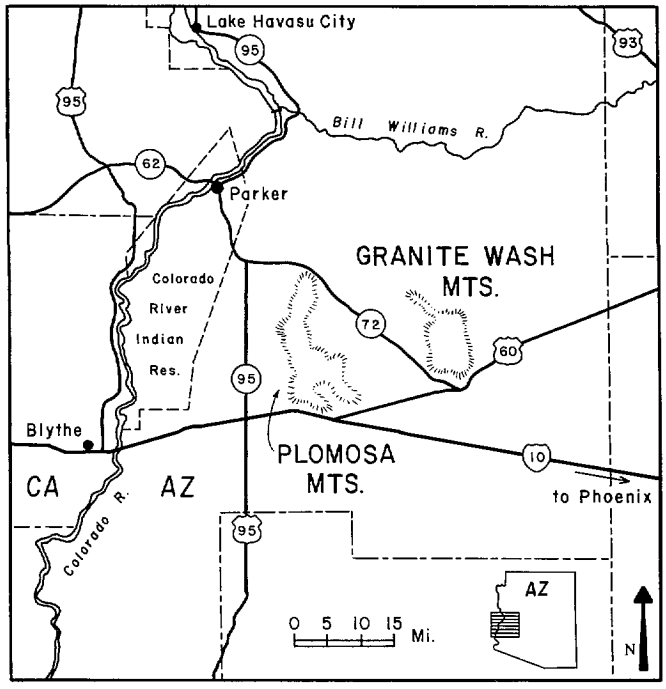

Figure 1. Location map of Granite Wash and Plomosa Mountains, Arizona.

The Future of the United States Copper Industry:

Part Two. The Consumption Side

*by Richard Newcomb**

Is the U.S. losing its comparative advantage in copper metal production to other countries? In this second of two articles economic trends in and the future of the U.S. copper industry are examined. Part one (*Fieldnotes*, Fall 1983) was an analysis of the formidable problems of the domestic industry on the supply side related to depletion, environmental and safety regulations, higher wages, and other factors. It demonstrated that, in general, Western copper mines, by adopting new smelting technology, can expand at well below the incremental costs required for new mines abroad, even in the richest mining districts. Therefore, when the rates of growth in world copper consumption resume as predicted, the $1.40-$1.50 per-pound price necessary for new capacity abroad will make it profitable to continue or expand domestic metal production. Some smelters may have to be relocated and, as a result, mining may cease in some places. But on average the Western copper reserves will remain an important and competitive source of new metal output if there is growth in demand. Will, however, markets grow at rates or in ways that foster the growth and profitability of U.S. copper fabricators? In this concluding part of the analysis, attempts will be made to answer these demand-site questions.

COPPER DEMAND, SUBSTITUTION, AND TECHNOLOGICAL CHANGE

Copper is widely used because of its high conductivity and resistance to corrosion, properties which give it strong comparative advantages in electrical uses, plumbing, and ordnance. About 80 percent of all copper demands are related to high conductivity, a factor which impels the use of copper in electrical wire or heat transfer systems. The other 20 percent of usage is related to its durability and convenience (malleability, etc.) in construction tubing, sheet metal, or durable mill products. Exhibit 11 is the industry's breakdown of recent annual U.S. consumption of mill, foundry, and powder products including alloy materials plus direct use of new and old scrap. Forecasts of copper's share in the future in these selective markets are generally based on the assumption that there will be continued use at these established "intensities." In contrast to publicity the industry has given to the increasing copper-production costs, it has not widely publicized its apprehension over inabilities to maintain shares of traditional markets in competition with other sources or materials, especially the lightweight metals and super-alloy steels.

For a long time the industry has believed that low, stable copper prices relative to aluminum and steel alloys must be maintained in order for copper to be competitive with other metals. This implies that demand for copper is "highly elastic", i.e., rather sensitive to small changes in the price of copper. Variable or rising copper prices may induce users to switch to alternative materials or designs. The major integrated brass and wire mill producers also dread the cyclical swings in copper demand which result in corresponding price changes. Whenever there is stagnation in the heavy utility and construction industries as exists currently, in durable investment goods such as machinery, and in the auto and transportation industries until recently, the copper producers are largely dependent on residual ordnance, inventory, and export demands. Inventory demands revive normally as the user industries recover from recession. The U.S. is open to imports, but exports of mill products from the United States are prohibited by tariffs and non-tariff barriers in most countries. Japan and Europe are especially unwilling to accept the level of U.S. copper products that the U.S. mill advantages dictated in the past. For these reasons, it is not clear than an industry strategy of focusing on price stability or on the cost of copper per pound relative to rival metals can preserve markets for domestic copper producers. This is particularly true when one considers the openness of U.S. markets to sizeable imports of copper-intensive final goods, such as automobiles from Europe or electronic consumer goods from Japan. All these factors result in reduced copper use and in a reduced share in world production for the U.S.

The emphasis on price stability in order to insure against customer switching has led U.S. producers to maintain prices that were commonly well below the world spot-market prices. This is reflected by the large gap between U.S. producers' price and price quoted on the London Metal Exchange (LME) for extended periods. This behavior is curious because during such periods, of course, the major U.S. producers have to forego profits and ration copper. Buyers, on the other hand, unable to secure copper, are given an incentive to switch to aluminum-intensive alternatives quite independent of the increase in

EXHIBIT 11

U.S. CONSUMPTION OF COPPER MILL, FOUNDRY, AND POWDER PRODUCT[1] BY END USE (IN THOUSAND SHORT TONS)

End Use	1970	1973	1976	1979
Electrical	770	902	724	893
Construction[2]	817	1090	854	1076
Machinery	612	699	526	617
Transportation	294	443	418	437
General	440	496	399	502
TOTAL	2933	3630	2921	3525

Source: Copper Development Association, Inc., Sousa (1981).

[1] Refined copper plus alloy materials plus direct new and old scrap.
[2] Includes building wire.

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the price of imported copper. Indeed, the switch away from copper to the light metals has been occurring while the price of copper has been falling relative to that of rival materials, because of the lower cost performance of new replacement technologies. Thus, a key factor for analysis of demands by the industry should be the impact of technological change, and the changes in engineering associated with *system* optimality and total user cost.

For example, in power transmission systems the switch away from underground cables intensive in the use of copper and lead, to overhead cables intensive in aluminum, took place despite aluminum's poorer conductivity and rising price. The switch occurred because the final cost per unit of power transmitted by the overhead systems fell below that of ground installations. More currently, the switch to composite materials and aluminum radiators in automobiles reflects the technological change to high-temperature combustion, which aids emission control and also eliminates weight. The overall result is a higher performance automobile with lower variable and fixed costs for the user. The elimination of conventional copper radiators is but a part of the system redesign.

In the U.S. currently, 60 percent of the demand for copper is tied to electrical uses. However, copper is being replaced by steel-core aluminum cable in power transmission, by aluminum in magnet wire, transformers, and switch-gears, and by silicon chips and fiber optics in electronic circuits. Copper is being replaced by thinner gauge wire in communication systems, and by improvements in myriad alternate designs, such as multiplexing via pulse-code modulation to upgrade capacities in junction circuits and trunk lines. Fiber-optic cable systems for communication, using glass fibers as conductors, can carry far greater volumes of traffic than equal-sized copper cables. Microwave towers, satellites, and waveguide systems also replace long-distance communication systems using copper. In construction, copper can be displaced by polyvinylchloride tubing, and in transportation by thinner walled and narrower tubing of aluminum, steel, or plastic. These materials in a variety of new systems are resulting in increasing substitution for copper in hydronic thermal applications. Military uses of copper as a percent of strategic materials demands also continue to decline.

The complexity of these substitutions due to technological changes brings into question the historic concerns of U.S. producers that stabilizing the price of copper at low levels relative to rival materials is sufficient to insure the constant use of copper in traditional applications. The simplest way to sort out the various influences on intensity of use is to combine engineering with economic analysis. In the short run, technology and plant investment are fixed, so that only within relatively narrow limits can a change in the price of a metal inspire much substitution. However, substitution becomes somewhat easier in the long run. Technological changes can shift demands up or down, as can cyclical changes in the user industry and changes in Gross National Product (GNP). Studies show that many manufacturers can successfully alter material usage if given enough time to react to shortages or higher prices of materials which become scarce. In any event, it is clear that to estimate the total consumption of primary copper one has to aggregate all sorts of influences and varied sectoral coefficients of use. Electric, construction, and transportation demands are cyclical. Furthermore, scrap recycling rates and imports vary over time. Thus, the rate of a given industry's copper consumption depends on a host of factors including business cycles, government policies, and an economy's stage of development. Materials substitution may take place at more rapid rates in the U.S. because most research is done here and replacement trends are often more advanced here than abroad. Without attempting to sort out the fundamental causes of substitution over time, one can speculate, as did Malenbaum (1977), that the declines in intensity of copper use in the U.S. are due to the advanced stage of industrialization. In contrast, developing countries have rising copper-usage rates. From this perspective, the administration of prices, by U.S. firms, below world market levels in an attempt to maintain copper-market shares appears futile.

An implication is that demands for copper may be overestimated if forecasters assume that conditions that prevailed in the past will remain constant. Despite this, most projections incorporate this assumption and predict growth on that basis (Exhibit 12). They also characteristically ignore cyclical influences. Detailed information on the distribution by sector of copper demands in Europe and Japan is not readily available. However, a recent study by Leontief and others (1982) confirms that forecasters in these countries, like those in the underdeveloped countries, assume constant use rates and are concerned primarily about deficits in supply. The higher coefficients observed abroad are partly due to the inavailability of cheap plastics and aluminum, the unfamiliarity or reluctance of manufacturers to risk a decline in quality, which may attend the adoption of new methods and materials, and lags in the diffusion of innovations abroad. Higher coefficients may also be attributed to the early stage of a country's industrialization, or to the growth in exports of copper-intensive goods, such as automobiles or electronic equipment. Whatever the causes, there is no reason to believe that high coefficients of use will persist in those countries as they follow the U.S. course. I have, therefore, in Exhibit 13, modified the estimates of world demand outside the U.S. that were made by Leontief and others. By fixing growth in

EXHIBIT 12

WORLD REFINED COPPER DEMAND FORECASTS, YEAR 2000 (IN MILLION SHORT TONS)

Study	United States	Rest of World	World
Bureau of Mines[1]	3.5	16.0	19.5
Malenbaum[2]	3.5	15.0	18.5
SRI[3]	4.2	16.9	21.1
Fischman[4]	3.4	14.6	18.0
Australian MEP[5]	2.9	15.7	18.6
Leontief[6]	3.7	20.0	23.7
Newcomb[7]	2.5	12.3	14.8

Sources:
1. Schroeder and Jolly (1980)
2. Malenbaum (1977)
3. cited by Sousa (1981)
4. Fischman (1980)
5. Australian Mineral Economics Pty, Ltd. (1979)
6. Leontief and others (1982)
7. Exhibit 13, this article

the developed countries at historical rates observed in the U.S., I have reduced the forecast world consumption of copper from 25 million to 14.8 million tons in 2000.

This prediction is much lower than those on which others have based forecasts of future capacity expansion, especially in Latin America. If considerable new world capacity results, copper from underdeveloped countries could be "dumped" in U.S. markets, further disturbing domestic producers.

EXHIBIT 13

WORLD REFINED COPPER SUPPLY AND DEMAND FORECAST, YEAR 2000 (IN MILLION SHORT TONS)

Supply	No. Am.	Lat. Am.	Demand Pacific	Africa	Soviet	Europe	TOTAL SUPPLY
No. Am.	2.7					.6	3.3
Latin Am.	.1	.8	1.1		.1	1.9	4.0
Pacific			1.2				1.2
Africa			1.0	.2	.2	2.0	3.4
Soviet Bloc					2.7		2.7
Europe						.2	.2
TOTAL DEMAND	2.8	.8	3.3	.2	3.0	4.7	14.8

Note: Author has assumed that world demand for refined copper will grow at rates approximate to forecast U.S. total demand growth. Supply shares are as estimated for producing countries on the basis of production costs.

Another implication of this analysis is that short-run costs (because they reflect supply and demand shifts, or "lags", and thereby affect the profitability expectations of investment decisions) should determine prices rather than historical average costs. The appropriate market for marginal costs pricing are the spot markets, such as the LME.

Between 1960 and 1980, as was illustrated in part one, U.S. producers, ignoring marginal costs in the rest of the world, set prices along a second tier or path closer to the historical average costs then existing in the industry. This created a two-tiered pricing system in which U.S. producers lost substantial profit and which discouraged expansion and renovation in the domestic mines and mills.

PRICE FORMATION IN THE COPPER INDUSTRY

U.S. producers did not follow the short-run fluctuations of the world free-market price, but instead chose to maintain the trend of long-range average cost, partly because they believed that short-run conditions would adjust quickly. However, as described above, they may have been motivated primarily by the fear that important copper markets would be lost if the industry myopically tried to profit from the wide fluctuation and rise in world prices. The government encouraged low, stable prices by manipulating its stockpile and threatening the industry during the Kennedy and Johnson administrations. Noting that, somehow, major firms were able to administer a lower price and ration copper, Henry Houtakker, Chairman of President Nixon's Council of Economic Advisors, viewed this attempt at apparent average-cost pricing as collusion by the integrated companies to limit competition in the brass and wire markets. Antitrust action was threatened and was followed by some rise in U.S. producers prices. Throughout, both the Japanese and U.S. Governments attempted, by stockpile manipulation, to keep copper prices below levels dictated by the international metal exchanges.

In retrospect, because foreign firms with low average unit costs in Africa garnered large profits abroad, the failure to raise prices resulted in large losses to U.S. producers. The size of economic rents foregone can be estimated. If one assumes that 13 million tons of U.S. copper were underpriced, U.S. firms lost half or more of the difference between LME and producers' prices from 1965 to 1975. Thus $3.5 to $7.0 billion in revenues was lost by major U.S. producers, and an even larger sum was earned by firms abroad due to the phenomenon of two-tiered pricing. Although some profits were recovered in higher brass-mill prices obtained by integrated U.S. firms, the U.S. losses hurt the industry's ability to refurbish its outmoded plant, while the higher world prices assisted in sustaining very high cash flows on new copper projects abroad. Mill-product prices and scrap prices were higher in Japan and the Organization for Economic Cooperation and Development (OECD) countries than in the United States. However, U.S. firms were unable to export mill products to Japan or the OECD countries because of trade barriers. This experience, even under the simplified analysis employed here, draws attention to the very different mineral policies of the U.S. and other countries.

DIFFERING U.S. AND FOREIGN MINERAL POLICIES

National monopsonies (trading companies with exclusive buying rights) and national producer monopolies or cartels are accepted abroad. The U.S. government, in contrast, has until recently ignored the presence of international combinations and frowned on domestic combinations. European and Japanese buyers' cartels have traditionally been assisted by their governments in negotiating favorable arrangements with the newly nationalized copper industries in producing countries. Expansions have thereby been encouraged, with higher LME prices and higher rates of return accruing to the foreign producers. Meanwhile, the U.S. government's acquisition of abundant copper inventories helped to keep domestic prices down and to create a large discrepancy between free world LME and the U.S. producers' price. This led ultimately to the confiscation of U.S. mines abroad. In Latin America, countries such as Chile and Peru, which are host to U.S. firms, felt deprived of taxes on profits that would have been obtainable had their copper been priced on the LME market. In Africa, the hosts to already nationalized European firms were more cooperative because they could expand their markets at the higher prices afforded by LME-based contracts. At one time, the Johnson administration negotiated with U.S. firms to permit the release of Chilean copper for world market sales, replacing the ore with equal tonnages of stockpiled domestic copper. Such measures helped prevent U.S. prices from rising, but did little to ease the poor relations between U.S. subsidiaries and their hosts. In contrast, European companies negotiated diplomatically and assisted host countries with the expansion of their mines.

During all these years U.S. brass-mill products and electrical equipment were not welcome in the Common Market or Japan, which sought to protect their domestic fabricators. Prevented from extending metal trade by high

tariffs and non-tariff barriers, U.S. firms participated abroad only in ore development ventures. As confiscation of mines abroad occurred, major U.S. firms were increasingly restricted to their domestic markets. At the same time, antitrust actions prevented the large copper firms from increasing their domestic market shares. Thus little incentive for growth existed; the major U.S. copper firms stagnated. Instead of exporting during periods of excess capacity at home, domestic firms abandoned the home market to increased imports and secondary metal whenever excess demands occurred. Thus, even though U.S. copper prices were considerably below world prices, declining growth, world trade, and profits resulted from domestic policies. Recently attitudes toward discriminatory foreign country trade practices have begun to change in the United States. However, this occurs at a time when short-run downward shifts in demand, combined with U.S. monetary policies, have complicated the long-run prospects for U.S. copper producers.

THE FUTURE OF U.S. FIRMS

Part one of this paper demonstrated that domestic U.S. copper mining firms do not have disadvantages in resources or technology that would prevent them from competing vigorously for domestic smelted-product demands. Experience with barriers to trade over the past thirty years also confirms that U.S. copper fabricators maintain comparative advantages in both wire and brass-mill products over the rest of the world, including most European and Japanese producers. Nonetheless, differences in the relationships between government policy and the behavior of firms here and abroad have brought about condiditons of zero growth for domestic firms while both mining and copper fabrication have boomed abroad. Because of the high ratios of fixed to variable costs, without the prospect for domestic growth in smelter products, U.S. firms are reluctant to replace their old smelter technology with energy- and labor-efficient alternative technologies. Currently strict emissions policy and increased costs for both labor and fuel make the variable costs of the obsolete smelters too high for them to be competitive. This is occurring at a time when high-interest-rate policy makes the fixed cost of replacement to comply excessive. Yet U.S. firms retain sufficient long-term advantages over expansion costs abroad to encourage the replacement of their outmoded reverberatory technology and, in some locations, even to resume the smelting of foreign concentrates. Will these firms do so?

The answer depends on what is done to remove the interference of governments, including our own, on capital markets, final goods markets, and access to free trade. World demands will undoubtedly not come close to the projections of the OECD nations or the U.S. Department of Interior recorded in part one, which foresee 18 to 25 million tons of copper consumption by 2000. More likely, world demands will reach levels of only 15 million tons by that date. U.S. metal demands should rise under the same assumptions also, but the U.S. firms are not likely to share in this growth because present currency and trade restrictions discourage industry reinvestment plans.

As long as U.S. fabricators face restrictions on the export of wire and mill products to the rest of the world, while imports of autos and other items cut their home coefficients of use significantly, they face zero-growth prospects at best. These prospects are further dimmed by high-interest U.S. monetary policy, which greatly slows the corporate investment and residential construction associated with the major copper-consuming sectors. In contrast, producers abroad have two notable advantages. First, neither their metal exports nor their copper-intensive final goods face restrictions on entering U.S. markets. Of equal or greater importance, the high-interest policy of the U.S. overvalues the dollar relative to costs in the exporting country. Prominent industrial economists variously estimate the disadvantage to U.S. producers to be 30-35 percent on average traded goods. Copper metal imports, however, come primarily from Latin American countries with currency disparities much greater than average due to the hyper-inflation policies pursued there. Thus, the sol (Peru) and the peso (Mexico and Chile) are undervalued by an additional 30-50 percent vis-a-vis the dollar. This means that copper exports paid in dollars, even at low current prices of $.67 per pound, yield 65-85 percent more purchasing power to the exporter in those countries. The industry has made much of the tendency of nationalized or subsidized foreign mines to overproduce during recession and over-expand on subsidized loans during boom periods. However, in the light of currency disparities and the terms-of-trade distortions obtaining under current monetary policies of these trading countries, the dollar equivalent of exports in Chile, Peru, and Mexico in terms of pre-devaluation pesos or sols ranges from $1.10 to $1.25 per pound. As long as overvalued currencies are available from exports to the U.S., mines in those countries will have realization prices close to the new facility expansion costs estimated in part one. Certainly most existing capacity will be quite profitable and incremental capacity worth considering.

To the extent that only the U.S. dollar's overvaluation is involved, the problems of U.S. copper fabricators are not dissimilar to those faced by other basic industries. Like steel, copper may find imports coming from foreign mills at economic scale competing freely with domestic production at uneconomic scales from obsolete facilities. Yet domestic fabricators will not be permitted to export new mill products abroad should they opt to replace and relocate their old facilities. In the case of fabricators, some new mills would favor new locations accessible to both Pacific basin or Europen markets as well as domestic users. This would cause realignments of some smelter capacity, which may, in turn, be open to foreign ores or concentrates.

Monetary policies responsible for high interest rates and the associated exchange-rate disparities are admittedly short-term in nature. Clearly, if they persist over a long period, they will encourage establishment of compensating U.S. tariffs or subsidies in an increasing number of traded goods. What can be predicted about the effects of such distortions given the present environment of world metals trade in which there are so many asymmetries?

The average impact of dollar overvaluation can be estimated by noting the 35 percent distortion estimated above for U.S. exchange rates, which apply to all traded goods. As long as the burden of inflation control falls on monetary policy alone, high interest rates will depress U.S. copper demands. At the same time, they will raise the value

of exports to foreign copper producers by 23¢ per pound.

The specific impact of greater than average undervaluation in the case of Chile, Peru, and Mexico can also be estimated. Each has devalued its currency by 50 percent or more and offers producers greater than average disparity with the dollar. In these major sources of export copper, the realization price of copper sold in the U.S. includes a premium ranging from 43 to 58 cents per pound.

In the early days of Western mine development, copper firms responsed to dramatic changes in the peso/dollar exchange rate by pegging miners' wages to copper prices. It is curious to see this expedient resorted to now by tough or "creative" bargaining. In addition, companies have asked for tax relief. Finally, tariffs on imported copper equivalent to the exchange distortions estimated above might be requested. Past tariffs on lead and zinc, quotas on oil, and differential realization prices for intra- and interregional gas sales are reminders that the U.S. government has frequently yielded to pressures for regulation of mineral markets. The result would be a rise in the price of smelter products inside the U.S. to levels between $.90 and $1.48 per pound.

In the Eastern mill regions, tariffs and non-tariff barriers to copper products from Japan or Europe, similar to existing barriers or subsidies in those countries, can also be adopted. The minimum distortion of such measures is indicated by the current level of tariffs abroad, which average 5-10 percent in Japan and the Common Market countries on brass- and wire-mill products from the U.S. The maximum distortion required is indicated by the higher initial tariffs, 25-40 percent, maintained on U.S. imports by those countries in the immediate postwar period. The presumption is that as these levels have been reduced they have been replaced by non-tariff barriers. The distortion is many times the transportation costs of U.S. brass-mill products for higher valued exports. Finally, policies subsidizing U.S. exports can be considered.

The problem with all these restrictive policies in the long run is that they bring mercantilist protection to inefficient firms. Of course they also bring an end to apparent U.S. disadvantages in copper production, and would, therefore, encourage investment in U.S. mines and mills. They may also bring retaliation in other U.S. markets.

The best alternative, therefore, is not U.S. discrimination, but efforts to end discrimination against U.S. products in the rest of the world. Under more liberal trade conditions, nationalized firms abroad would lose their special protected positions. However, to date, little has been done to remove the non-tariff discrimination against copper products from the U.S. in the developed or underdeveloped countries.

As a result, U.S. mines, although possessed of real comparative advantages approximating 30-50¢ per pound over new mines abroad, appear to have equal or greater *disadvantages* vis-a-vis their major producing rivals: Peru, Mexico, and Chile.

CONCLUSIONS

It is my opinion that neither industry nor government has paid adequate attention to the changing character of international copper markets. Now that the significance of world market conditions to U.S. producers is more generally recognized, U.S. firms are tempted to urge policies of market interference similar to those practiced in the Common Market countries, Japan, or underdeveloped regions. A new regionalism has surfaced in the U.S. among mining firms, which are now recommending protective tariffs, delays in smelter regulations, and the like. Some authorities are protesting the granting of the bank loans under special conditions for use in the expansion of foreign copper mines. The industry recently challenged the International Monetary Fund (IMF) loans to developing countries. Industry pressures have also been placed on Western mine labor to reduce wages and on legislatures to reduce taxes. In the Eastern fabricating sector, advocates of "industrial policy" have broadly suggested subsidies for mill reinvestment.

Such policies address mining as if it were independent of fabricating, but most brass and wire mills in the East are fully integrated back into Western mines and smelters. More data are required for a full analysis of what the impact of specific regional protection would be on the industry as a hole. Nonetheless, crude measures of the levels of distortion created by protection can be provided.

If Latin and African countries expand as now proposed, any future slowdown of world copper demands will probably create serious excess supply. While protected Japanese and European markets will be unaffected or receive cheaper copper, the U.S. will be seriously affected. These prospects should encourage U.S. companies to modernize and to press aggressively for an end to foreign restrictions on their wire- and brass-mill products. In addition they should work progressively to redesign copper back into many of the systems from which the metal has been eliminated. This would not prevent the influx of cheap metal imports into Eastern mills, but the growth of mill capacity in both East and West would open up additional markets for Western mines as well as foreign concentrates.

Failing the effort to remove foreign tariffs and other barriers, the Western states may proceed independently to seek relief for mines by tax reductions or extensions of variances which permit pollution. Most economists regard these last measures as "second best". Variances are regarded as the least efficient because the obsolete Western furnace capacity carries with it very high labor and energy inefficiencies (costs). This means that high penalties are associated with any delay in the adoption of cleaner and more efficient new technologies.

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BUREAU OF GEOLOGY AND MINERAL TECHNOLOGY OPEN-FILE REPORTS RELEASED IN 1983

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The students of the Department of Geosciences, University of Arizona will be holding their 12th annual GEOSCIENCE DAZE on March 28-30, 1984, in the Senior Ballroom of the University of Arizona Student Union. Over 40 papers will be presented on various aspects of geosciences. The public is cordially invited and no admission is charged.

Fieldnotes

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GEOLOGIC FEATURES OF NORTHEASTERN ARIZONA

by Stephen J. Reynolds

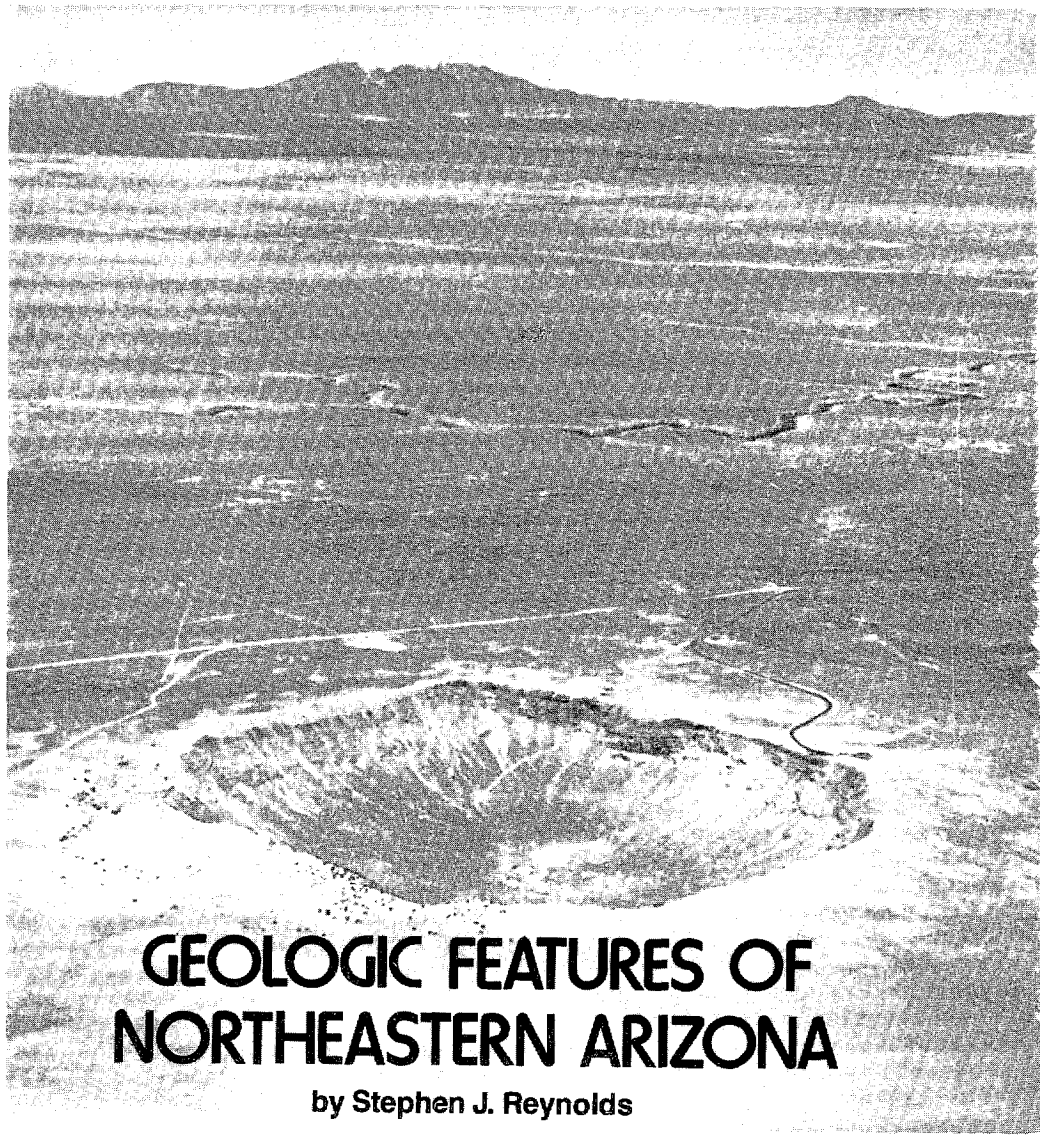


Figure 1. Aerial photograph of Meteor Crater with San Francisco Mountains in background. Photo: Meteor Crater, Northern Arizona.

Introduction

Northeastern Arizona has long been famous for its rich endowment of scenic beauty and natural wonders, such as the Grand Canyon, Monument Valley, and Meteor Crater (Figure 1). How did such features form? What is the geologic story behind the scenery? Geologists and park naturalists are often asked these and other questions. Most answers are not simple. Behind every landscape are hundreds of subtle and not-so-subtle geologic controls. An entire geologic story exists within every pinnacle, canyon, and rock layer. What concerns us here is not the detailed script of the geologic story, but the overall plot.

This article contains a short summary of the geology of northeastern Arizona, followed by a "character sketch" of the area's best known geologic features. A list of general references is included for those interested in learning more about the geology of this fascinating region.

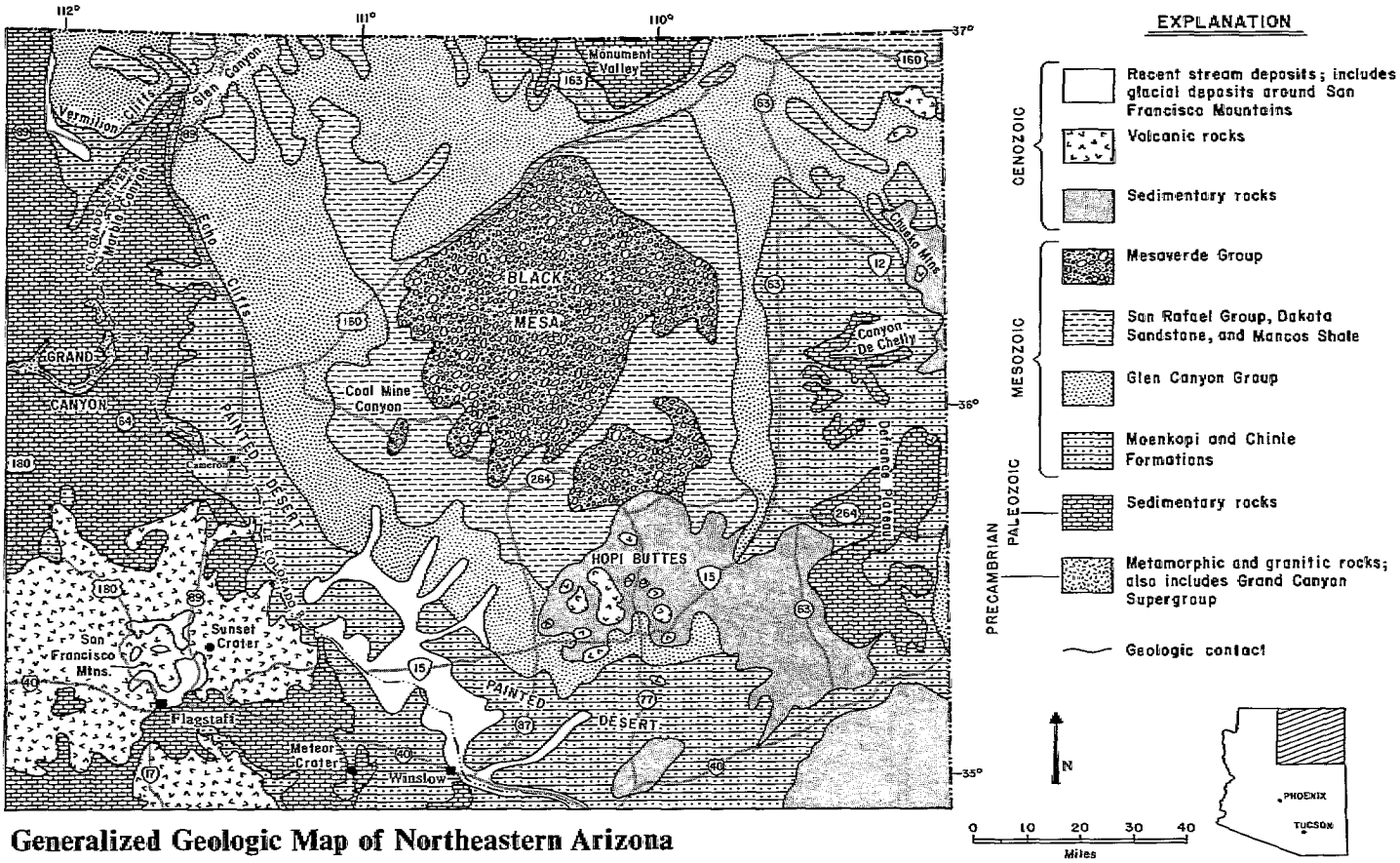
Geologic History of Northeastern Arizona

Northeastern Arizona is part of the Colorado Plateau physiographic province, a region of wide-open spaces and breath-taking vistas. Landscapes of the Colorado Plateau are dominated by broad plains or plateaus that are interrupted by a series of mesas, cliffs, and deep canyons. The spectacular scenery of the region is mostly due to erosion of a sequence of flat-lying sedimentary formations. Differences in color and resistance to erosion between adjacent sedimentary layers create the colorful, stair-stepped appearance that is so typical of the region.

The geologic history of northeastern Arizona began in the Precambrian Era nearly two billion years ago (see Figures 2–4), when sediments and volcanic rocks were deposited in oceans and scattered volcanic archipelagos. These deposits were buried to great depths and converted into metamorphic rocks by high temperatures and pressures. They were intruded by magma (molten rock) that solidified into granite. These ancient metamorphic and granitic rocks represent the first step in the long process of building the continental crust of Arizona. They have been buried by thousands of feet of younger sedimentary rocks and are presently exposed only in the bottom of the Grand Canyon and in small areas of the Defiance Plateau. Drill holes by oil companies indicate that Precambrian metamorphic and granitic rocks underlie essentially all of northeastern Arizona.

Around 1.1 billion years ago, parts of the region were invaded by shallow seas, in which sedimentary rocks of the Grand Canyon Supergroup were deposited. Sedimentation was locally accompanied by emplacement of basaltic intrusions and by eruption of basaltic lavas. Episodes of

IN THIS ISSUE Oil and Gas Activity, BGMT 1981 Summary, Federal Agencies in AZ, Regional Events



Generalized Geologic Map of Northeastern Arizona

Figure 2. Geologic map (modified from Cooley, 1967).

faulting occurred during and after deposition of the Grand Canyon Supergroup.

After a prolonged period of erosion that lasted about 500 million years, early Paleozoic seas invaded most of Arizona and resulted in the deposition of limestone, shale, and beach sands. Within northeastern Arizona, these sedimentary rocks are exposed only in the lower walls of the Grand Canyon. However, they reappear from beneath their cover of younger rocks along the Mogollon Rim to the south and the Grand Wash Cliffs to the west.

In the latter half of the Paleozoic Era, about 300 million years (m.y.) ago, northeastern Arizona was the site of shallow seas, extensive mud-flats, and large fields of sand dunes. The resulting sequences of limestone, shale, siltstone, and sandstone are exposed in the upper walls of the Grand Canyon and are partially exposed in Monument Valley, Canyon de Chelly, the Defiance Plateau, and the Mogollon Slope.

In the early part of the Mesozoic Era (225 m.y. ago), the region consisted of a broad coastal plain on which the Triassic Moenkopi Formation was deposited. Subsequent mountain building and volcanism to the south contributed steam-carried debris and volcanic ash that were deposited as the Chinle Formation. The Chinle Formation is exposed in the Painted Desert and in brightly colored lower slopes of the Vermilion Cliffs, Echo Cliffs, and Paria Canyon. The next sedimentary formations deposited, those of the Glen Canyon Group, consist of red, orange, and white sandstone and siltstone that represent ancient sand dunes and river deposits. They form the upper parts of the spectacular Vermilion Cliffs, Echo Cliffs, and Paria Canyon and are also widely exposed around Glen Canyon, Navajo National Monument, and the northern Chinle Valley. These formations locally contain numerous dinosaur footprints and bones.

During the middle part of the Mesozoic Era (180–110 m.y. ago), more sandstone, siltstone, and shale were deposited by streams, wind, and ocean currents. These rocks, assigned to the San Rafael Group, Dakota Sandstone, and Mancos Shale, are most widely exposed around the periphery of Black Mesa, such as in Coal Mine Canyon. In Black Mesa, they are overlain by late Mesozoic sandstone, siltstone, and shale of the Mesaverde Group, which contains important coal resources. These rocks were deposited in deltas and shallow, retreating seas.

Near the end of the Mesozoic, the Colorado Plateau and the rest of Arizona were subjected to stresses that folded the sedimentary layers and caused some areas to be uplifted relative to others. By

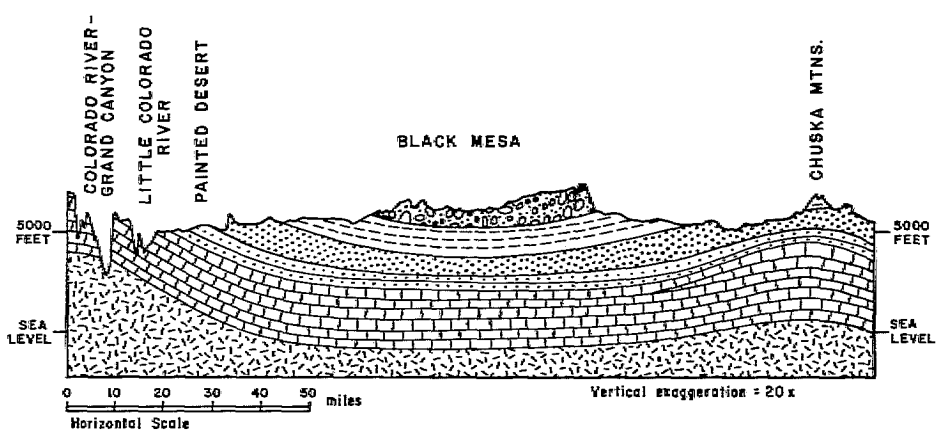


Figure 3. Geologic cross-section from Grand Canyon to Chuska Mountains (modified from Oetking and others, 1967).

the start of the Cenozoic Era (65 m.y. ago) the seas had completely retreated from northeastern Arizona, never to return. The oldest Cenozoic rocks are igneous intrusions and wind-deposited sandstones, found in and around the Chuska Mountains. Much younger lake beds, stream deposits, and volcanic rocks accumulated south of Black Mesa and the Defiance Plateau. In latest Cenozoic time, intense volcanism constructed the San Francisco Mountains near Flagstaff. Volcanism has continued until very recently, as evidenced by the formation of Sunset Crater in 1065 A.D. The present episode of canyon cutting probably started within the last 10 million years.

Grand Canyon

Any discussion of geologic features of northeastern Arizona should include the Grand Canyon (Figure 5). The canyon is perhaps the most magnificent erosional feature on earth. It is a remarkable 277 miles long, up to 18 miles wide, and approximately one mile deep. The canyon was carved by the Colorado River and its tributaries, and widened by landslides, rockfalls, and various other types of erosion. Within the geologist's conception of time, the canyon is a relatively young feature formed within the last 5 to 10 m.y. However, rocks exposed in the canyon walls are much older, ranging in age from almost two billion years to less than 250 m.y.

As in most geologic settings, the oldest rocks are at the bottom. The dark, inner gorge of the canyon has been incised into Precambrian metamorphic and granitic rocks that are nearly two billion years old, almost half as old as the earth itself. The metamorphic rocks represent sedimentary and volcanic rocks that were buried to great depths and metamorphosed by high temperatures and pressures. Some granitic rocks were probably formed when the metamorphic rocks were melted.

The top of the Precambrian rocks is marked by an unconformity, a surface that represents a period of erosion that, in this case, lasted up to 500 m.y. The unconformity is overlain by Paleozoic sedimentary rocks that form the conspicuous layering in the canyon walls. The sedimentary rocks were deposited between 600 m.y. and 250 m.y. ago in shallow seas, deserts, and meandering rivers. They consist of resistant sandstone and limestone that form major cliffs, and easily eroded siltstone and shale that form gentle slopes. This sequence of sedimentary rocks is not restricted to the Grand Canyon, but extends beneath most of the Colorado Plateau of northern Arizona. Rocks of similar age reappear at the surface along the Mogollon Rim, Monument Valley, and near Canyon de Chelly.

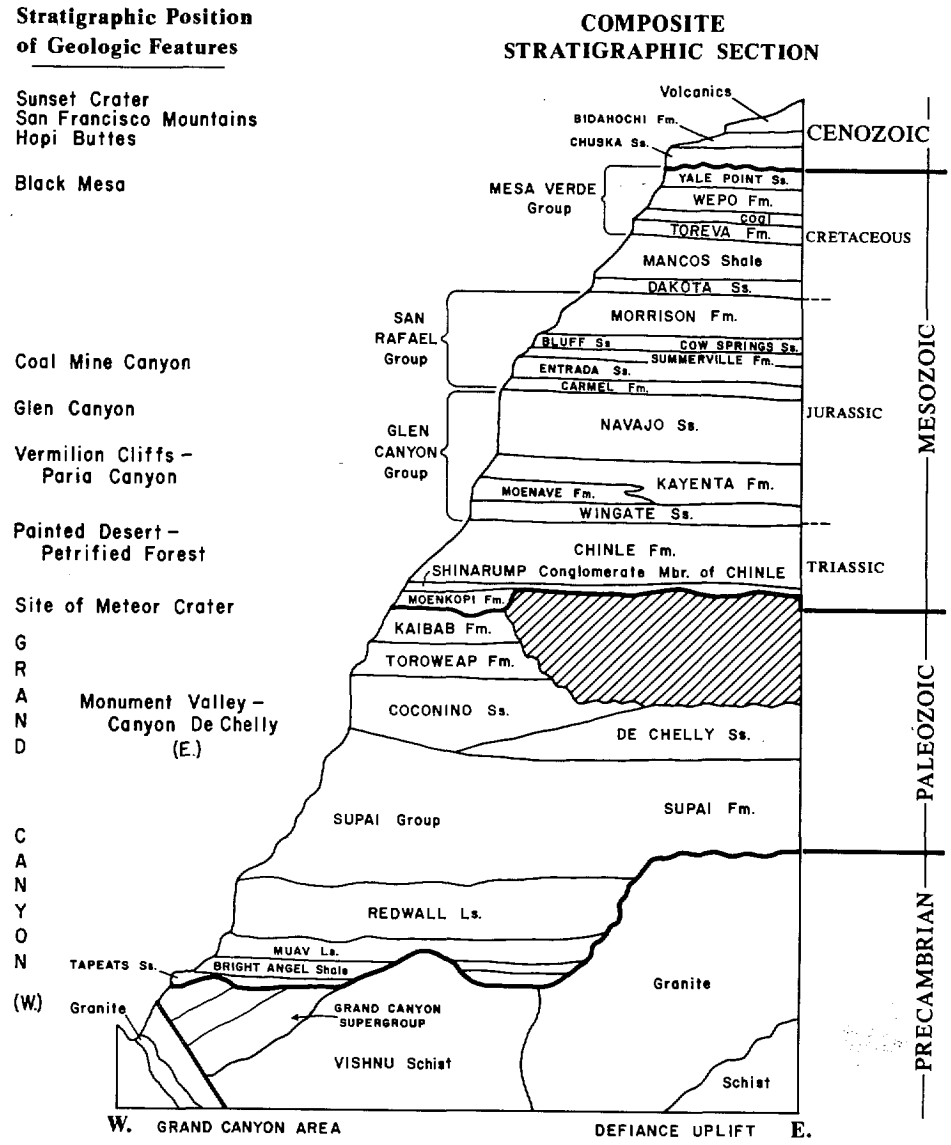


Figure 4. Composite stratigraphic section of northeastern Arizona (modified from Petrified Forest Museum Association, 1980, geologic cross-section along Interstate 40).

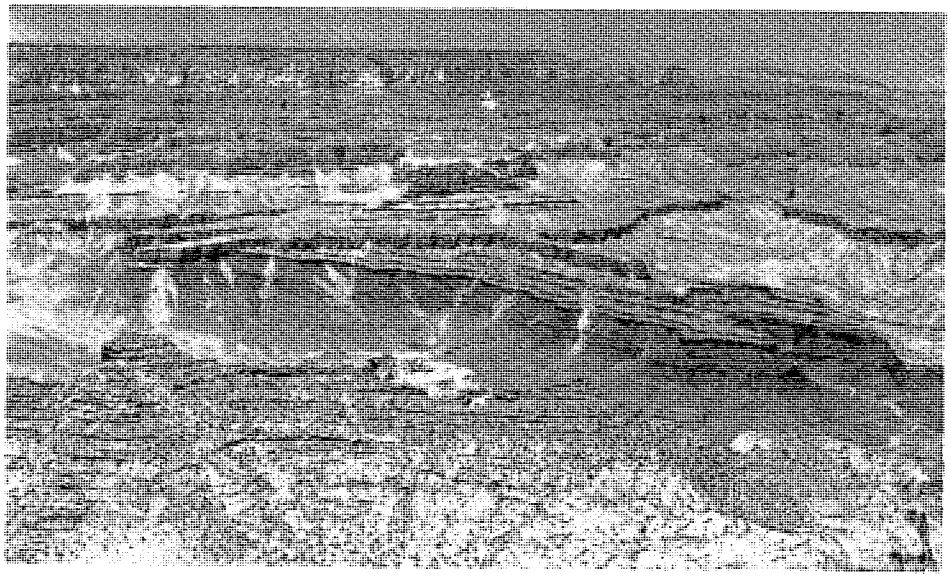


Figure 5. Eastern Grand Canyon. Note unconformity between tilted strata of Grand Canyon Supergroup (of late Precambrian age) and overlying sedimentary rocks of Paleozoic age. Photo: S. Reynolds.

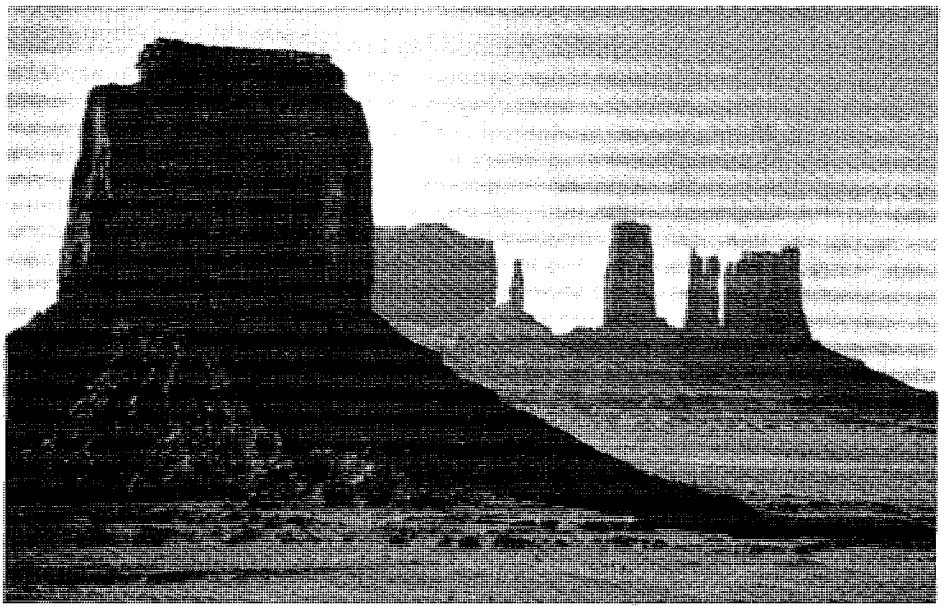


Figure 6. Monument Valley at sunset. "Monuments" are composed of slope-forming shale, cliff-forming De Chelly Sandstone, and cap-rock of Shinarump Conglomerate. Photo: S. Reynolds.

Monument Valley

Monument Valley is another of nature's masterpieces of erosion (Figure 6). The trademarks of Monument Valley are spectacular, steep-sided mesas, buttes, and pinnacles that rise abruptly from a nearly featureless plain. The scenery of the valley is dominated by three main sedimentary layers that are similar in age to those exposed in the upper walls of the Grand Canyon. The lowest layer is composed of easily eroded shales and mudstones that occur on the gently sloping pedestals around each monument. The middle and most prominent layer, referred to as De Chelly Sandstone, forms a brightly colored orange and red cliff. The sandstone was originally deposited as sand dunes approximately 270 m.y. ago. It is overlain by a thin, protective cap of Triassic Shinarump Conglomerate that represents ancient stream deposits. All three layers once extended continuously over the entire Monument Valley region, but they

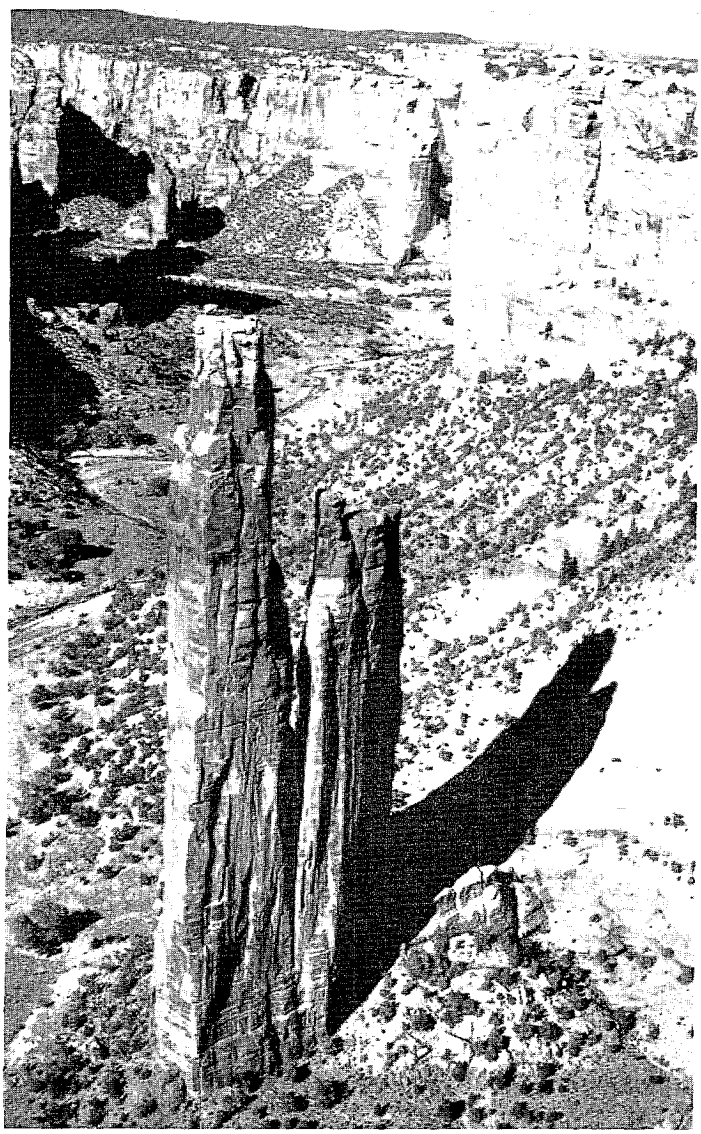


Figure 7. Canyon de Chelly and Spider Rock. Photo: S. Reynolds.

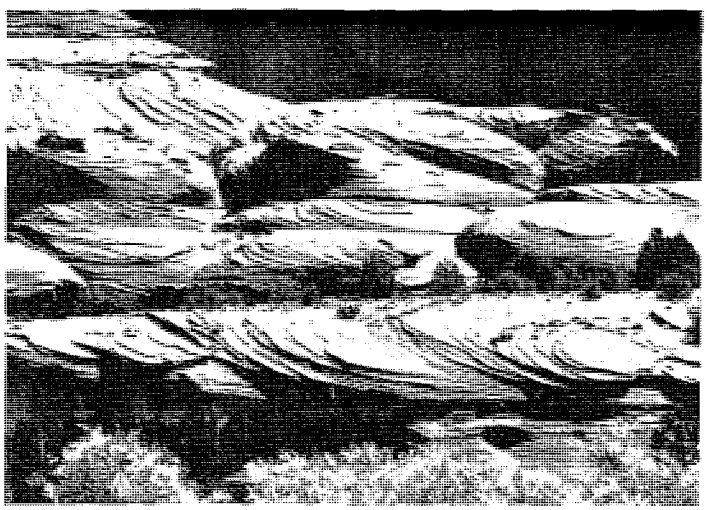


Figure 8. Cross-beds in De Chelly Sandstone, Canyon de Chelly. Photo: S. Reynolds.

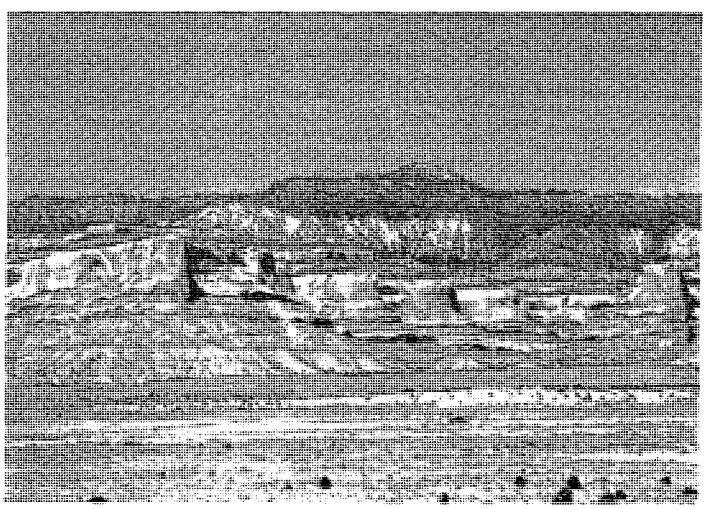


Figure 9. Chuska and Lukachukai Mountains. Strata low on the flanks of the mountains are mostly sandstones of Mesozoic Glen Canyon Group. Overlying rocks are younger sedimentary and volcanic rocks of Mesozoic and Cenozoic age. Photo: S. Reynolds.

were gradually removed from most areas by erosion within the last 10 m.y. The "monuments" are remnants of the layers that erosion left behind.

Canyon de Chelly

Beautiful Canyon de Chelly (pronounced de-shay) is the topographic opposite of Monument Valley. Whereas Monument Valley contains isolated monuments rising above a low-relief plain, Canyon de Chelly is a deep cleft within a gently inclined plain (Figure 7). The steep-sided canyon was formed as streams eroded down through a sequence of resistant rocks that are partly the same sedimentary formations that comprise Monument Valley. Canyon de Chelly contains a lower, slope-forming layer, a middle cliff of brightly colored De Chelly Sandstone, and an upper protective cap of tan and brown Shinarump Conglomerate. The middle sandstone was formed as a part of the same field of sand dunes as the middle sandstone of Monument Valley. The original forms of the sand dunes are preserved in the rocks as a series of gently sloping layers or cross-beds (Figure 8). The cross-beds represent the fronts of ancient sand dunes and can be used to determine which way the wind was blowing when the sand was deposited 275 m.y. ago.

The actual canyon was not formed until much more recently, probably within the last several million years. At famous Spider Rock (Figure 7) the canyon is over 1,000 feet deep and 3,000 feet wide. The canyon walls become progressively lower downstream to the west because the resistant cap rock and underlying layers gently slope in that direction. The prehistoric Anasazi Indians constructed White House and other dwellings within recesses and alcoves in the sheer vertical walls.

Chuska and Lukachukai Mountains

The Chuska and Lukachukai Mountains, some of Arizona's least publicized scenic attractions, are familiar to many geologists as the site of Arizona's largest oil field. Both mountain ranges are located in northeastern Arizona, near the New Mexico border. The Chuska Mountains are an impressive, mesa-like range that reaches elevations of over 9,700 feet and affords excellent views of Shiprock and Canyon de Chelly. The rugged and colorful flanks of the range are composed of red- and orange-colored sandstone and siltstone of early Mesozoic age (see Figure 9). These strata are successively overlain by younger, light-colored sedimentary rocks and a dark-colored cap of Cenozoic volcanic flows. Rocks beneath the Lukachukai Mountains were found in 1967 to contain significant oil deposits. This oil field has accounted for nearly 90 percent of Arizona's total oil production. Since its discovery, it has yielded over 16 million barrels of oil, which is less petroleum than Arizona presently consumes in four months.

Black Mesa

Black mesa is one of the largest geological entities of Arizona (Figure 2). It is a more-or-less circular feature approximately 60 miles in diameter, with an area of 3,200 square miles. The mesa is a saucer-like erosional remnant of sedimentary rocks of the Cretaceous Mesaverde Group that once covered much of northeastern Arizona (Figure 3). These rocks overlie and are significantly younger than the Paleozoic sedimentary layers of the Grand Canyon, Monument Valley, and Canyon de Chelly. In fact, drilling by oil companies indicates that Paleozoic rocks are buried nearly a mile below the surface of Black Mesa. Imagine the walls of the Grand Canyon with yet another mile of rocks on top!

Sedimentary rocks of the Mesaverde Group are not as brightly colored as the older rocks that surround Black Mesa. The Mesaverde Group is composed of tan and gray sandstone, siltstones, and shales that were deposited in shallow seas, along beaches, and by streams (Figure 10). These rocks contain Arizona's largest known deposits of coal. The coal was formed from plants that accumulated in swampy or marshy environments. The plant-rich layers were buried by younger stream and beach deposits, and were gradually converted into coal. Black mesa coal was first used for fuel by prehistoric Indians and will be a major energy source for the southwest U.S. many years into the future.

Coal Mine Canyon

Some extremely beautiful landscapes occur in and around Coal Mine Canyon, west of Black Mesa. Scenic badlands topography has been formed in varicolored sandstone and siltstone of the Mesozoic San Rafael Group (Figure 11). A coal seam within the sedimentary layers was evidently ignited by lightning and burned to produce brightly colored rocks resembling slag from a furnace. Locally, shale layers directly above the coal seam display exotic colors and abundant oyster fossils. The somewhat eerie aspect of the landscape is accentuated by legends of a silvery ghost that haunts the area during full moons.

Hopi Buttes

Landscapes south of Black Mesa are dominated by dark-colored buttes that stand above a surrounding red- and tan-colored terrain (Figure 12). The oldest rocks exposed near the Hopi Buttes are red-colored sandstone and siltstone of Mesozoic age. These rocks are overlain by light colored layers of Late Cenozoic sandstone, siltstone, and mudstone that were deposited in ancient Lake Bidahochi approximately 5 m.y. ago. The lake beds locally contain fossil fish and larger vertebrates such as antelope, camels, and mastodons. These rocks are in turn overlain by dark-colored volcanic rocks that were erupted onto the floor of the lake. The volcanic rocks are mostly basaltic lava flows and pyroclastic deposits composed of ash, cinders, and larger fragments. Sedimentary layers derived from the volcanic rocks are relatively common. Some buttes are true volcanic vents, whereas others are simply capped by thin lava flows. The Hopi Buttes exist because the

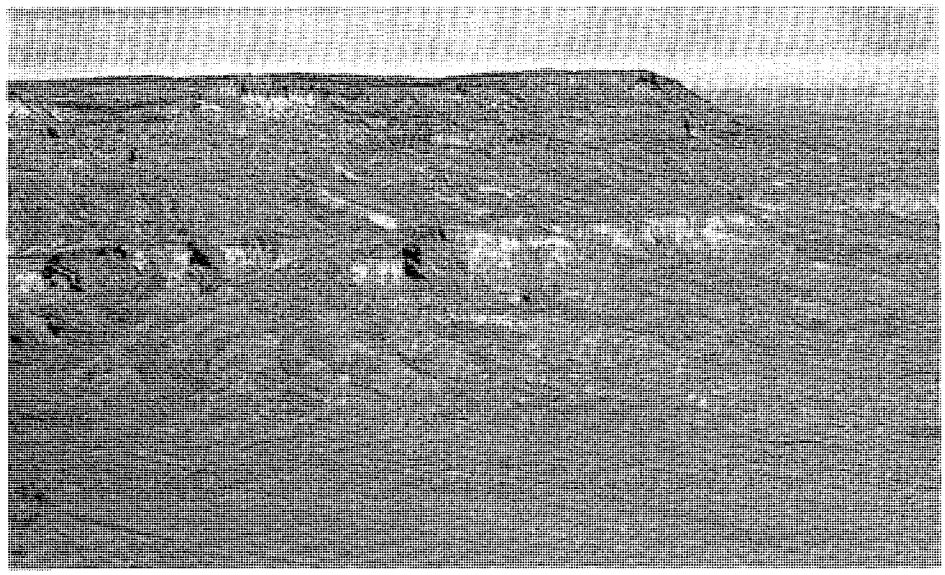


Figure 10. Mesaverde Group, Mancos Shale, and older strata on east flank of Black Mesa. Photo: D. Nations.

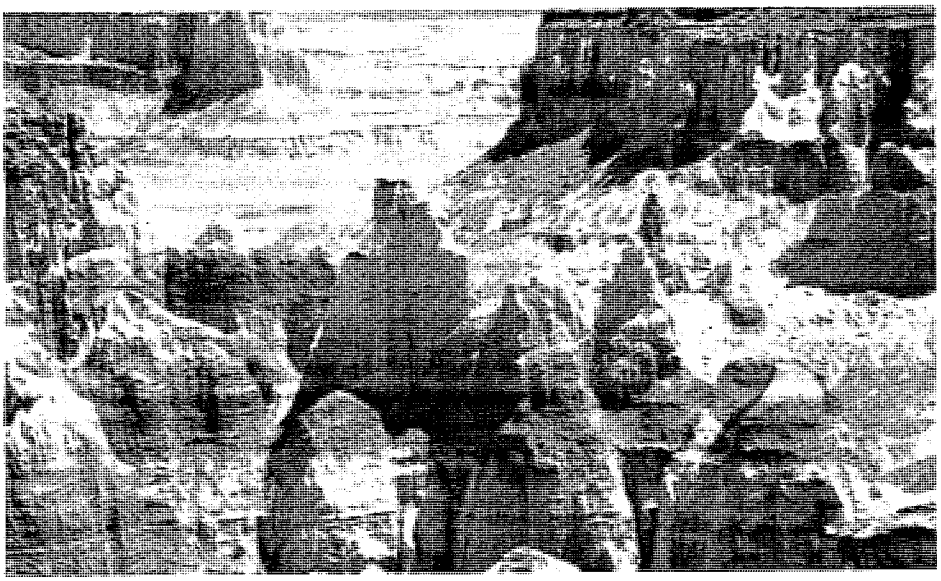


Figure 11. Coal Mine Canyon, west of Black Mesa. Badlands topography is developed in sedimentary strata of the San Rafael Group of Mesozoic age. Photo: S. Gillatt.

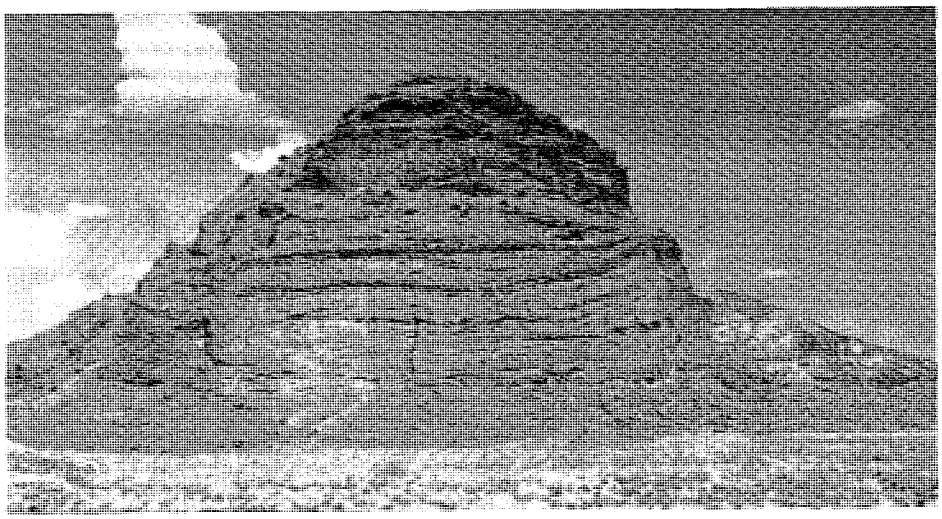


Figure 12. Typical Hopi Butte. Dark-colored butte is composed of late Cenozoic volcanic rocks that overlie, and are flanked by Mesozoic sandstones of the Glen Canyon Group. Photo: S. Reynolds.

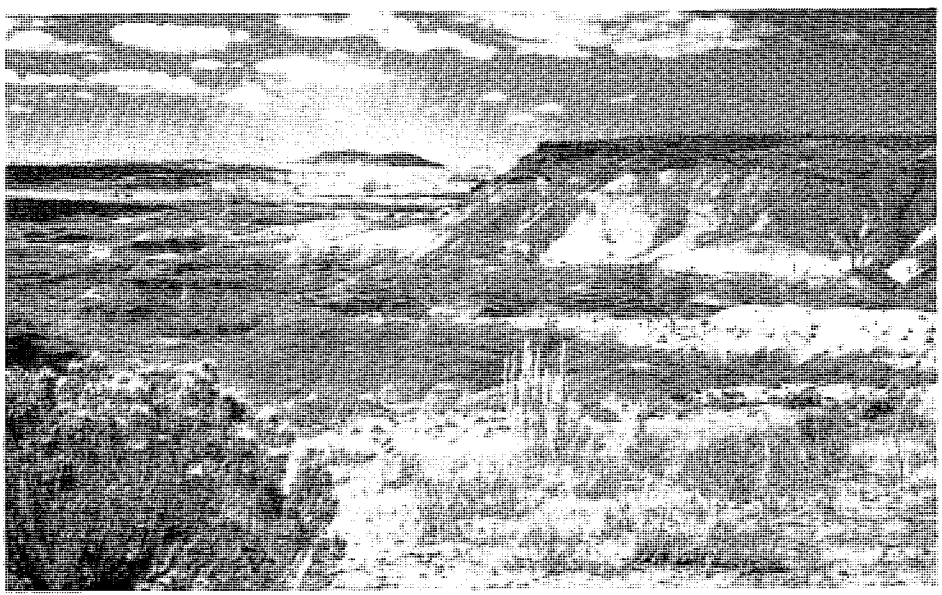


Figure 13. Typical landscapes developed in Chinle Formation of early Mesozoic age, Painted Desert. Photo: S. Reynolds.

volcanic rocks are more resistant to erosion than are the surrounding and underlying sedimentary rocks.

Painted Desert—Petrified Forest

Colorful landscapes of the Painted Desert lie mostly south and west of Hopi Buttes and extend along the Little Colorado River Valley from east of Holbrook to north of Cameron. This region is characterized by extensive, low-relief plains and a series of small cliffs, ledges, and rounded hills (Figure 13). Most of the Painted Desert is underlain by variably colored sandstone, siltstone, and shale of the early Mesozoic Chinle Formation. These sedimentary rocks were deposited by meandering streams that flowed north across the region some 200–250 m.y. ago. The red, orange, pink, and purple colors in the rocks are due to oxidized iron and manganese minerals. Many of the white and gray layers contain clays that were formed by the weathering and alteration of volcanic ash. The volcanic ash was evidently blown into the area from erupting volcanos to the west.

Figure 14. Petrified log in Chinle Formation, Petrified Forest. Log is several feet in diameter and over 30 feet long. Photo: S. Reynolds.

The Chinle Formation locally contains brightly colored petrified wood (Figure 14). The Petrified Forest is one of the world's greatest concentrations of large, petrified logs. The logs were originally transported northward into the area by flooding streams and were buried by successive layers of ash, mud, and sand. Ground water percolating through the sediments dissolved silica from the volcanic

ash and redeposited it in the buried logs, turning them to stone. Impurities of iron, copper, and manganese in the silica give the petrified logs their splendid color.

Meteor Crater

The tranquil appearance of the Painted Desert and Little Colorado River Valley is interrupted west of Winslow by a large, circular crater (Figures 1 and 15). This feature, well known as Meteor Crater, is over 4,000 feet wide and 550 feet deep. It is one of the most spectacular meteorite impact craters in the world. The crater was formed approximately 20,000 years ago when a nickel-iron meteorite crashed onto the flat surface of the Colorado Plateau at over 30,000 miles per hour. The meteorite is calculated to have been over 80 feet in diameter and to have largely vaporized upon impact. Sedimentary layers along the rim of the crater were upturned by the force of impact and were covered by debris blasted out of the crater. Numerous fragments of the meteorite have been found below the floor of the crater and on the surrounding plateau surface.

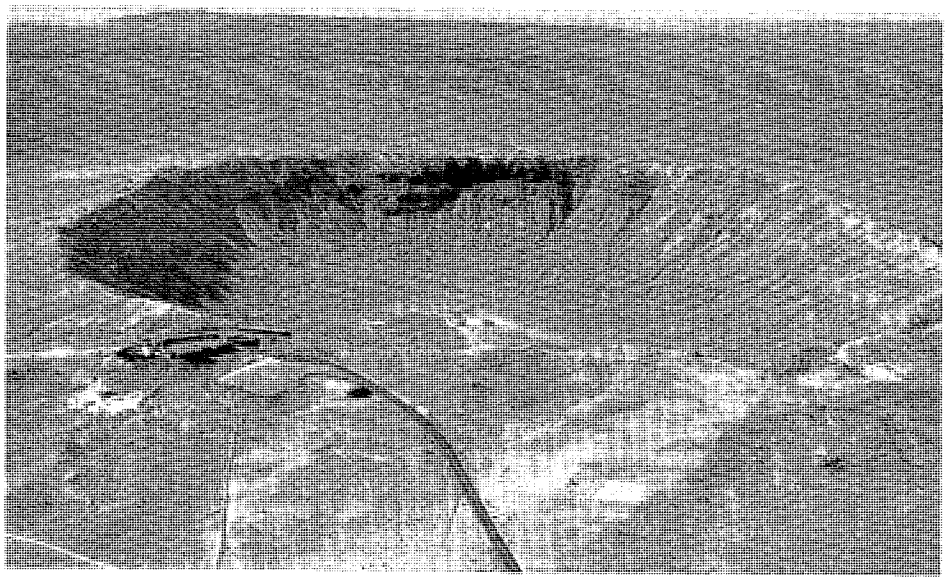


Figure 15. Meteor Crater. Walls of crater are composed of limestone and sandstone of late Paleozoic age. Rocks below floor of crater are shattered. Photo: Meteor Crater, Northern Arizona.

Sunset Crater

A different type of crater lies east of the San Francisco Mountains, approximately 30 miles northwest of Meteor Crater. Sunset Crater was produced by a volcanic eruption a little more than 900 years ago. The eruption, which occurred around 1065 A.D., marks the most recent volcanic activity in the San Francisco volcanic field. The 1,000-foot-high crater was formed when hot volcanic cinders were blown into the air, and then settled around the vent (Figure 16). Formation of the main cinder cone was accompanied by eruption of a dark, basaltic lava flow that occurs in Bonito Canyon. At the end of the volcanic episode, hot springs and vapors escaped from the vent and deposited brightly colored minerals near the top of the crater. These yellow, red, and orange minerals give the crater its color of a perpetual sunset.

Needless to say, the volcanic eruption had a profound impact on the local Indians. Prior to the eruption, Indians, now referred to as the Sinagua, lived around the San Francisco Mountains in pithouses. The spectacular, but ominous eruption prompted many Sinagua to flee the area. After the eruption, neighboring Indians, including the Anasazi, migrated into the area to farm on the moisture-retentive volcanic ash. Multi-room dwellings, such as those preserved at Wupatki National Monument, were constructed at this time. Relentless winds eventually stripped the soil of its beneficial volcanic ash, and the Indians abandoned Wupatki and neighboring villages.

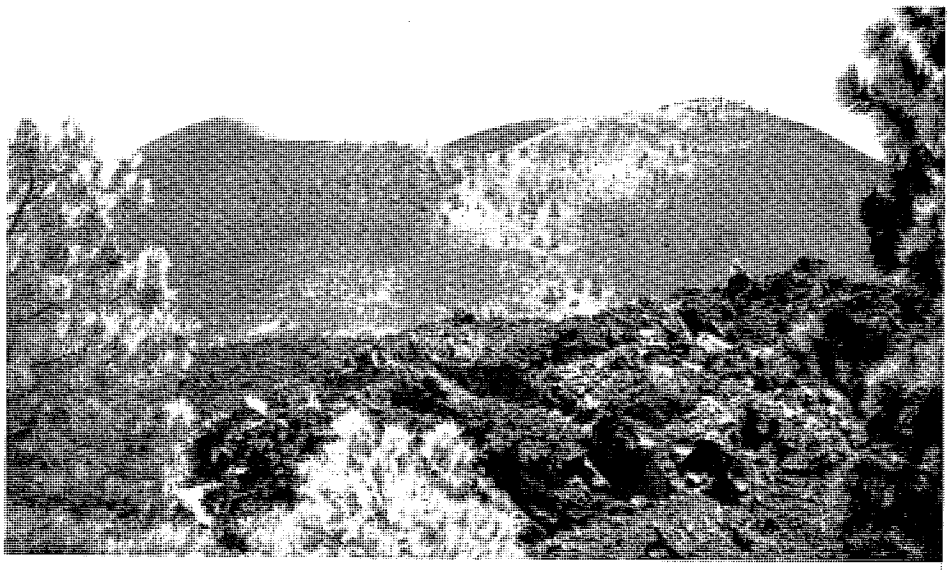


Figure 16. Sunset Crater with Bonito Lava Flow in foreground. Photo: S. Reynolds.

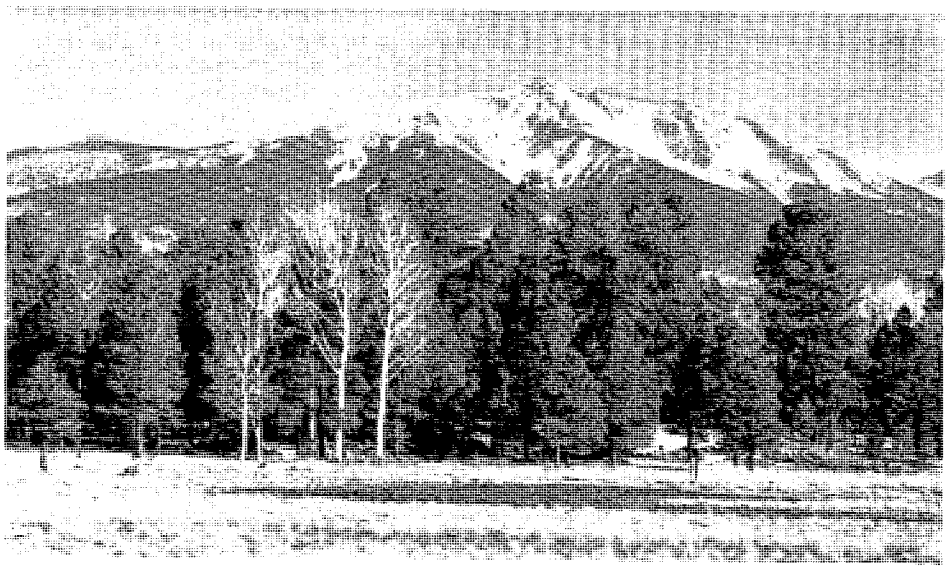


Figure 17. San Francisco Mountains from northwest. Photo: K. Matesich.

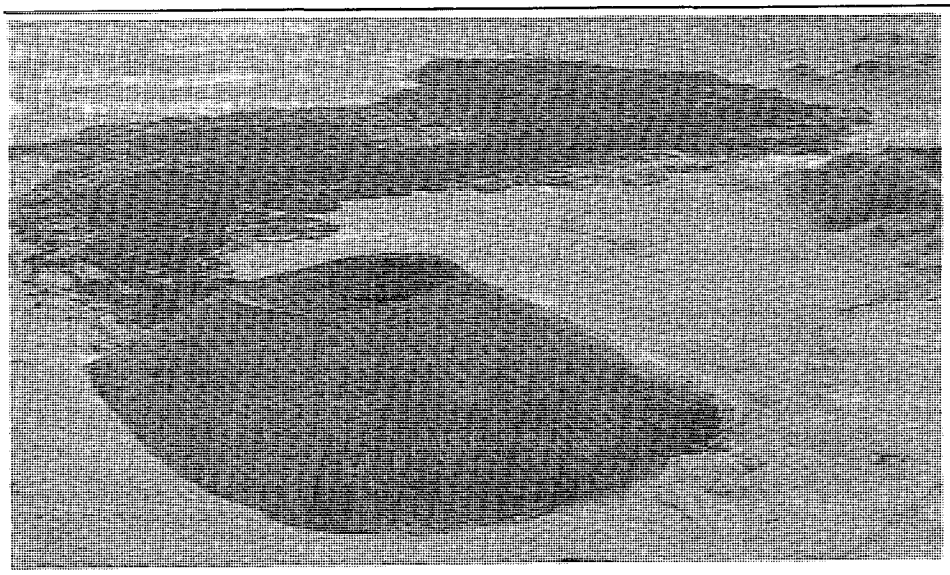


Figure 18. Aerial photograph of S P Crater and lava flow. Photo: D. Nations.

San Francisco Mountains

The San Francisco Mountains (or Peaks) are Arizona's largest stratovolcano and highest mountains (Figure 17). Humphreys and Agassiz Peaks reach over 12,000 feet in elevation and stand approximately a mile above the surrounding Colorado Plateau. The San Francisco Mountains were formed by successive eruptions of lava and pyroclastic debris within the last two m.y. The top of the volcano, which may have once been as high as 15,000 feet above sea level, has been lowered substantially by volcanic collapse and subsequent glacial erosion. The glaciers probably extended from near the crest of the peaks to near the floor of the adjacent plateau.

Surrounding the main peaks are a number of smaller volcanic vents. Elden Mountain, O'Leary Peak, and Kendrick Peak are volcanic domes similar in origin to the one presently forming in the crater of Mount St. Helens in southwestern Washington state. Numerous, small cinder cones are scattered around the higher peaks. Some of these, such as S P Crater, Sunset Crater, and Merriam Crater are recent and well preserved. Photographs of S P Crater and its accompanying lava flow appear in most introductory geology textbooks (Figure 18).

SELECTED REFERENCES

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Wilson, E. D., Moore, R. T., and Cooper, J. R., 1969, Geologic map of Arizona: Arizona Bureau of Mines Map, scale 1:500,000.

ARIZONA OIL AND GAS CONSERVATION COMMISSION 1981 Activity Report

by A. K. Doss Executive Director, Arizona Oil and Gas Conservation Commission

Considerable exploration-related activity occurred during 1981, as reflected in the number of drilling permits issued by the state and by the total footage drilled (see table below). However, one exploration drill hole, of particular interest to industry, proved to be a major disappointment. The Phillips Petroleum No. 1 State, near Tombstone, was abandoned after reaching a total depth of 10,561 feet. In spite of this casualty, the following table indicates a striking comparison between the years 1980 and 1981:

	1980	1981
Number of drilling permits issued	14	73
Total number of wells drilled	8	51
Total footage drilled	32,775	65,400
Number of oil test dry holes	7	9
Number of oil producers	0	6

The 51 holes drilled in 1981 represented oil and gas tests (15), geothermal resource tests (34), underground storage cavity well (1), and re-entry (1).

The six new oil producers are on the Navajo Indian Reservation. Five new development wells, drilled by Kerr-McGee Corporation in the Dineh-bi-Keyah field, produced an average of 200 barrels of oil per day. The sixth well is a wildcat drilled by Kenai Oil and Gas in Section 7, T. 40 N., R. 29 E. This well indicated a pump potential of 56 barrels of oil per day.

Geothermal gradient holes represented the largest number drilled, accounting for approximately 7,600 feet of drilling.

The increase in activity and production during 1981 will also be reflected in an increase of state revenues through taxes, rentals and commercial sales, as indicated in the following table (estimated on an annual basis for the next few calendar years):

OIL AND GAS REVENUES TO ARIZONA

Direct	
1. Advalorem taxes (10¢/ dollar on the gross sales of oil and gas production)	$1,312,500
2. Sales tax (2½% of the gross sales of oil and gas production)	400,000
3. Rentals to the state (state lands and ½ on federal lands)	16,000,000
	$17,712,500
Indirect	
Commercial sales (rent, food, clothing, fuel, trucking fees, trucking charges, recreation, etc), conservatively estimated	$600,000
Total Revenue	$18,312,500

The prognosis for 1982 is even better than 1981. Conceivably, footage drilled could exceed 100,000 feet. Phillips Petroleum has a six-well drilling program outlined, and other major companies, as well as large and small independents, have indicated interest in exploration drilling activity. This interest is scattered from the northwest corner to the southeast corner of the state.

BUREAU OF GEOLOGY AND MINERAL TECHNOLOGY
Summary of Activities during 1981

by Larry D. Fellows
Assistant Director and State Geologist
Bureau of Geology and Mineral Technology

Geologic mapping, CRIB*, salt, "young" faults, earthquakes, potential geothermal resources, COSUNA**, geologic road and river logs, and uranium resources: these subjects, and more occupied the staff at the Bureau of Geology and Mineral Technology (BGMT) during 1981. In addition, geologic data and general assistance were provided to hundreds of persons.

The BGMT, charged by statute to do scientific investigations and to provide information, functions as the state geological survey of Arizona. Forty-five states have geological surveys and no two are identical. In Arizona our mission is to do research and provide information about: 1) the state's geologic setting, 2) its mineral and energy resources, and 3) the overall impact of things geologic on land use and society.

INFORMATION AND ASSISTANCE

We endeavor to provide timely, accurate, geologically related information based on geologic mapping, field observations, research investigations, and data compilations and synthesis.

BGMT staff supply information and furnish assistance by:

1. Publishing and selling geologic studies, either over-the-counter or by mail order. (A list of available publications may be obtained free of charge.)
2. Maintaining a specialized geologic library for public and staff use. The library includes:
   a. Unpublished maps and reports prepared by BGMT and other agencies
   b. Maps and reports published by the BGMT, the U.S. Geological Survey (USGS), the U.S. Bureau of Mines, state geological surveys from adjacent states, and other state and federal agencies
   c. Selected theses on Arizona geology
   d. Index of theses on Arizona geology (1891–1978)
   e. Abstracts of talks and articles on Arizona geology (1960–1981)
   f. Some major geological bulletins, journals, and newsletters
3. Publishing *Fieldnotes,* our quarterly newsletter, which is available by subscription (free) or over-the-counter
4. Giving talks on various aspects of geology on request
5. Identifying rocks and minerals from Arizona
6. Storing drill cuttings from selected exploration holes for examination
7. Disseminating information by telephone, correspondence, and office visits

Projects Completed:

—BGMT open-file series established
—Index of geologic road and river logs (1950–1980) published as Circular 22

Projects in Progress:

—Index of theses on Arizona geology
—Index of published geologic maps

RESEARCH

Geologic Setting

To better understand the geologic setting, or framework, of Arizona, BGMT geologists study the earth's surface and subsurface to learn the distribution and characteristics of rocks and other earth materials. They also identify the earth processes that have been active, or may still be active (e.g., folding, faulting, erosion, metamorphism, intrusion, volcanism, etc.).

Projects Completed:

—Characteristics and correlation of rocks of Mississippian and Pennsylvanian age in Arizona; prepared as part of USGS project and published as BGMT Circular 21
—Four composite stratigraphic sections in the Basin and Range Province, completed as part of COSUNA project and placed on open file at BGMT
—Report on the 1887 earthquake, San Bernardino Valley, Sonora: summarizes intensities in various parts of the state, and other related phenomena such as rockfalls and liquefaction; funded by USGS, U.S. Nuclear Regulatory Commission (NRC), and BGMT; published by BGMT as Special Paper 3
—Final report to USGS and NRC on historical seismicity in Arizona; project funded by USGS, NRC, and BGMT; report placed on open file by BGMT; copies available for purchase
—Compilation of existing gravity control points at 1:250,000 scale and two milligal contour interval; work done by University of Arizona, Department of Geosciences, as part of BGMT geothermal assessment project; partial funding provided by U.S. Department of Energy (DOE); maps available for examination or purchase at BGMT; 1:500,000 scale map may be obtained from the Department of Geosciences
—Geologic mapping along the Salt River from Roosevelt Dam downstream to Granite Reef Dam; project funded by U.S. Bureau of Reclamation; maps on open file at BGMT

Projects in Progress:

—Geologic mapping in Harquahala, Little Harquahala, and South Mountains
—Mapping of faulting and volcanic activity during past 15 million years; funded by USGS and BGMT
—Mapping of earth materials of Quaternary age (last 3 million years); final product will be 1:1,000,000 scale map of state; project funded by USGS and BGMT
—Map showing rock outcrops of Laramide age (70–50 million years ago)
—Comprehensive catalog of earthquakes that occurred or were felt in Arizona; project funded by USGS, NRC, and BGMT; being prepared for publication by BGMT

Mineral and Energy Resources

BGMT staff conduct studies on the occurrence, characteristics and origin of mineral and energy resources and provide information useful in mineral exploration, mining, and processing.

Projects Completed

—Occurrence of radioactive minerals in Arizona; funded by DOE; placed on open file at BGMT with copies available for purchase

Projects in Progress:

—Assessment of potential geothermal resources in Arizona; final report being prepared
—Map showing geothermal anomalies and data; will be printed by the National Oceanic and Atmospheric Administration
—Geothermal bibliography and index in Arizona; to be published by BGMT as Circular 23
—Occurrence and production of molybdenum in Arizona; project funded by USGS; data entered in CRIB; in technical review

continued on page 12

***Computerized Resources Information Bank**
****Correlation of Stratigraphic Units of North America**

Earth Science Information

Federal Agencies in Arizona

Data and information about Arizona's earth materials, mineral and water resources, and earth processes are available from various state and federal agencies. A list of state agencies and some of the services and products they provide was included in the June 1981 issue of *Fieldnotes*. Some federal agencies are listed here to guide those who might need additional information or assistance about these and related matters.

DEPARTMENT OF AGRICULTURE

FOREST SERVICE—Regional Office

Office of Information
517 Gold Ave., S.W.
Albuquerque, NM 87102
505/766-2444
There is no state office. Contact should be made with specific Forest Headquarters or District Ranger offices, listed below.

Services and products:

Provide information on
—Resources on national forest lands
—Mineral exploration and leasing
—Lands closed for mineral entry
Sells forest maps

National Forest Headquarters:

Apache-Sitgreaves National Forest
Box 640
South Mountain Ave.
Springerville, AZ 85938
602/333-4301
Nick W. McDonough, Forest Supervisor
District Ranger Offices in Alpine, Clifton, Lakeside, Overgaard, Snowflake, and Springerville

Coconino National Forest
2323 E. Greenlaw Lane
Flagstaff, AZ 86001
602/779-3311, ext. 1441
Neil R. Paulson, Forest Supervisor
District Ranger Offices in Flagstaff, Happy Jack, Rimrock, and Sedona

Coronado National Forest
301 W. Congress
Federal Building
Tucson, AZ 85701
602/792-6483
Robert L. Tippeconnic, Forest Supervisor
District Ranger Offices in Douglas, Nogales, Safford, Sierra Vista, and Tucson

Kaibab National Forest
800 South Sixth Street
Williams, AZ 86046
602/635-2681
Leonard A. Lindquist, Forest Supervisor
District Ranger Offices in Fredonia, Tusayan, and Williams

Prescott National Forest
344 South Cortez Street
P.O. Box 2549
Prescott, AZ 86302
602/445-1762
Donald H. Bolander, Forest Supervisor
District Ranger Offices in Camp Verde, Chino Valley, and Prescott

Tonto National Forest
102 S. 28th Street
P.O. Box 29070
Phoenix, AZ 85038
602/261-3205
James L. Kimball, Forest Supervisor
District Ranger Offices in Carefree, Globe, Mesa, Payson, Roosevelt, and Young

SOIL CONSERVATION SERVICE

3008 Federal Building
230 North First Ave.
Phoenix, AZ 85025
602/261-6711

Verne M. Bathurst, State Conservationist
Donald R. Phillips, Assistant State Conservationist—Programs
Douglas S. Pease, State Soil Scientist

Services and Products:

Library of soil maps and reports (available for examination; no checkout)
Published soil surveys available for distribution
Generalized soil maps for each county in Arizona
Major land resource areas and sub-resource areas in Arizona (maps)
Farmland maps for portion of Maricopa County
Information on soils and soil-mapping projects

Area Offices:

Flagstaff Area
Soil Conservation Service
2717 North Fourth, Suite 140
Flagstaff, AZ 86001
602/779-3311 or 779-1392
Charles R. Adams, Area Conservationist

Tucson Area
Soil Conservation Service
3241 Romero Rd.
Tucson, AZ 85705
602/792-6602
Joseph L. Knisley, Jr., Area Conservationist

DEPARTMENT OF INTERIOR

BUREAU OF LAND MANAGEMENT

Arizona State Office
2400 Valley Bank Center
Phoenix, AZ 85073
602/261-3706
Thomas J. Allen, Acting State Director

Services and Products:

Records of unpatented mining claims on federal lands in Arizona
Land ownership maps and other maps for sale (price list available)
Maps showing wilderness inventory information on Bureau of Land Management (BLM)-administered lands
Information on how to obtain leases and information about BLM-administered lands open or closed for mineral entry
Watershed characteristics of some BLM-administered lands

District Offices:

Arizona Strip District Office
Federal Building
196 E. Tabernacle
P.O. Box 250
St. George, UT 84770
801/673-3545
Billy R. Templeton, District Manager

Phoenix District office
2929 W. Clarendon
Phoenix, AZ 85017
602/241-2501
William K. Barker, District Manager

Yuma District Office
2450 Fourth Ave.
Yuma, AZ 85364
602/726-6300
H. Max Bruce, District Manager

Safford District office
425 E. Fourth Street
Safford, AZ 85546
602/428-4040
Fritz Rennebaum, District Manager

Kingman Resource Area of Phoenix District
2475 Beverly
Kingman, AZ 86401
602/757-4011
Roger G. Taylor, Area Manager

Lake Havasu Resource Area of Yuma District
P.O. Box 685
2049 Swanson Ave.
Lake Havasu, AZ 86403
602/855-8017
James May, Area Manager

BUREAU OF MINES

Intermountain Field Operations Center
Denver Federal Center
Building 20
Denver, CO 80225
Joseph B. Smith, Chief, 303/234-3918
Jimmie E. Jinks, Assistant Chief, 303/234-3740
George R. Schottler, Chief, Minerals Availability Section, 303/234-4161
Karl E. Starch, Chief, State Services Section, 303/234-6866
Lorraine B. Burgin, State Minerals Specialist for Arizona
Homer C. Stewart, Chief, Resource and Environmental Studies Section, 303/234-3930
Robert G. Dickinson, Chief, Mineral Land Assessment Section, 303/234-6755

Services and Products:

Information on the location and potential of mineral resources, exploration, development, and processing
Computerized system for assessing worldwide information on mineral resources through systematic engineering and cost evaluations for selected mineral properties
Identification and location of significant domestic operating, developing, and explored mines for selected commodities
Library of periodicals, state and federal reports, open-file reports, technical books and maps on mineral resources, mining, and processing.
Data files on mines and mining districts
Statistical information on state mineral production and mining activities

BUREAU OF RECLAMATION

Geology and Materials Branch
505 South 43rd Avenue
P.O. Box 6972
Phoenix, AZ 85005
602/261-4450
Rex A. Motsenbocker, Chief

Services and Products:

Information on
—Engineering properties of earth materials
—Subsidence due to groundwater withdrawal
—Ground-water levels along the Central Arizona Project aqueducts and storage dams
—Geologic setting and related factors in the Central Arizona Water Control Study Area
—Geologic factors related to safety of dams along Salt and Verde Rivers

GEOLOGICAL SURVEY—Geologic Divison

Western Region
345 Middlefield Road
Menlo Park, CA 94025
415/323-8111
G. Brent Dalrymple, Assistant Chief Geologist, Western Region

Services and Products:

Information about Western Region (Geologic Division) projects and activities in Arizona

GEOLOGICAL SURVEY—Geologic Division

Flagstaff Office
2255 N. Gemini Drive
Flagstaff, AZ 86001
602/779-3311
Gordon Swann, Deputy Assistant Chief Geologist

Services and Products:

Geologic library includes most U.S. Geological Survey (USGS) publications, as well as other geologic maps and reports
Information about status of geologic projects being done by geologists at Flagstaff office
Planetary data facility and library
Information about ordering lunar and planetary images and USGS publications

GEOLOGICAL SURVEY—National Mapping Division

Western Mapping Center
345 Middlefield Road, M.S. 31
Menlo Park, CA 94025
415/323-8111
Gene Napier, Acting Chief, Program Management

Services and Products:

Topographic maps, orthophoto quadrangles, and other related maps
Base maps and separates at various scales
Digital mapping
Information about status of mapping projects
Information on cost and availability of maps (address inquiries to National Cartographic Information Center, Menlo Park)

GEOLOGICAL SURVEY—Water Resources Division

Arizona District Office
Federal Building
301 W. Congress
Tucson, AZ 85701
602/792-6671
Robert MacNish, District Chief

Services and Products:

Basic water resources data (stream flow, ground-water levels, flood-prone areas, water use, springs, water quality)
Reports on earth fissures and subsidence related to ground-water withdrawal, surface and ground-water interaction, floods, consumptive use of water by vegetation, and ground-water supply and availability
Prepares data for flood warning
Maintains formal cooperative programs with Arizona Department of Water Resources and other state and federal agencies
Provides loan copies of published USGS water studies in Arizona

Subdistrict Offices:

Flagstaff Field Center (USGS)
Water Resources Division
2255 N. Gemini Drive
Flagstaff, AZ 86001
602/779-3311, ext. 1429
G. W. Hill, Field Office Chief

Phoenix Subdistrict office (USGS)
Water Resources Division
1880 Valley Bank Center
Phoenix, AZ 85073
602/261-3188
E. G. Nassar, Subdistrict Chief

Tucson Subdistrict Office (USGS)
Water Resources Division
Federal Building
301 W. Congress
Tucson, AZ 85701
602/792-6671
H. W. Hjalmarson, Subdistrict Chief

Yuma Subdistrict Office (USGS)
Water Resources Division
1940 South 3rd Avenue
P.O. Box 5774
Yuma, AZ 85364
602/783-2133
L. L. Werho, Subdistrict Chief

Bureau Activity Summary continued

—Occurrence and production of base and precious metals being introduced into CRIB; funded by USGS and BGMT

Impact of Things Geologic

In order to evaluate the impact of things geologic, one must first understand the geologic setting—earth materials, resources, and processes. Some processes (e.g., flooding, faulting, landslides, rockfalls, etc.) may be hazardous to inhabitants and destructive to structures. Certain other factors (steep slopes, thin soil cover, subsidence, shrinking and swelling clay, presence or absence of resources, etc.), although not hazardous, may limit use of land.

During 1981 BGMT geologists reviewed and evaluated reports on the potential for mineral resources in wilderness study areas, the geologic framework in proposed hazardous and toxic waste disposal areas, geologic factors along proposed Central Arizona Project canal routes, and the impact of various geologic factors on land use in Coconino County.

Projects Completed:

—Report on 1887 earthquake in San Bernardino Valley, Sonora; includes discussion on implications for seismic hazard in Arizona and recommendations to minimize earthquake losses
—Final report to USGS and NRC on historical seismicity in Arizona; includes commentary on seismic risk

Projects in Progress:

—Comprehensive catalog of earthquakes that occurred or were felt in Arizona; funded by USGS, NRC, and BGMT; will be published by BGMT
—Assessment of geologic hazards in Arizona; funded by USGS and BGMT; will include identification of areas in which potentially hazardous geologic factors occur

REGIONAL EVENTS

Illinois State Museum—Field Trip, Geology of the Grand Canyon, Colorado Plateau, Arizona and Utah; Springfield, June 28–July 9, 1982.

Geological Society of America—Penrose Conference
- Origin of Fluids and Metals in Porphyry and Epithermal Mineral Deposits, Dillon, Colo., August 8–13, 1982 (Deadline: April 20).
- Laramide Deformation of the Rocky Mountain Foreland, Billings, August 22–28, 1982.
- Sonoma Orogeny and Permian to Triassic Tectonism in Western North America, Winnemucca, Nev., September 8–14, 1982.

Utah Geological Association—Field Trip, Central Utah, Salt Lake City, September 20–22, 1982.

Fieldnotes

Vol 12 No 1 March 1982

State of Arizona ..... Governor Bruce Babbitt
University of Arizona ..... President John P. Schaefer
Bureau of Geology & Mineral Technology
Acting Director ..... William P. Cosart
State Geologist ..... Larry D. Fellows
Editor ..... Anne M. Candea
Illustrators ..... Joe LaVoie, Ken Matesich and Jenny Laber

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FIELDNOTES
From The Arizona
Bureau Of Geology And Mineral Technology

Volume 13 No 1 | Earth Sciences and Mineral Resources in Arizona | Spring 1983

ASBESTOS

Toward A Perspective

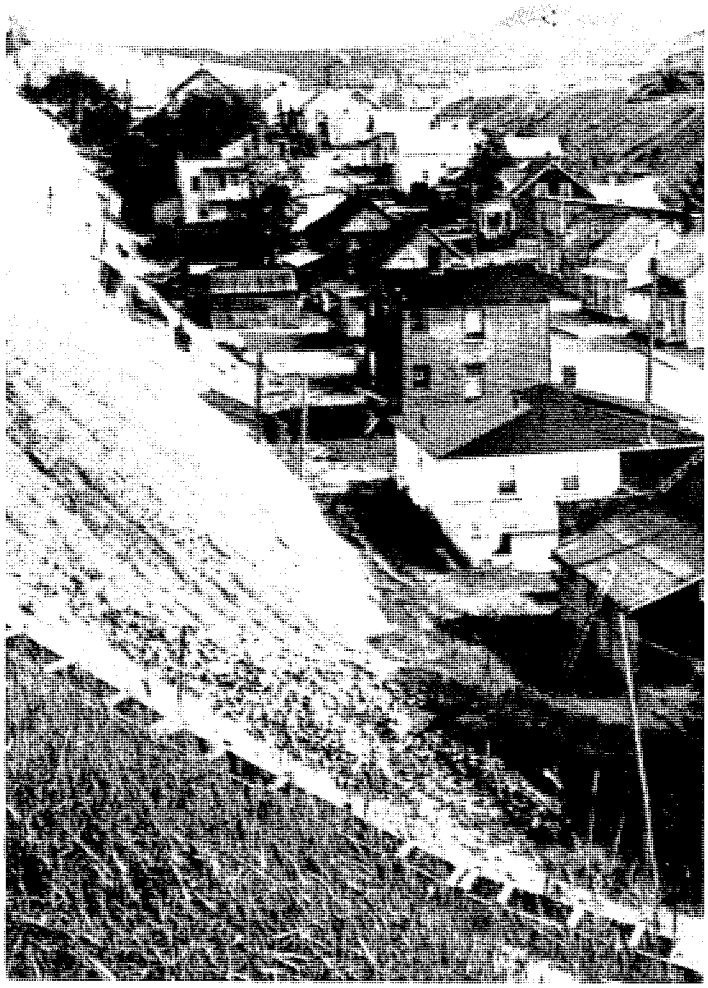
by H. Wesley Peirce, Principal Geologist
and
Meliton M. Garcia, Industrial Hygienist

Director's Comment: Asbestos has achieved international notoriety largely because of its reported carcinogenic (cancer-causing) tendencies. A dilemma exists because of a conflict between two issues: 1) negative effects related to public health, and 2) positive public benefits derived from asbestos use. Although positions have already been taken on this subject by many, it is our belief that enough uncertainties exist to encourage further research and discussion. The purpose of this article is to put current knowledge into perspective and to encourage additional analysis. [W.P.C.]

INTRODUCTION

Like the word "snakes", asbestos is not a scientific word. Both are lumping terms encompassing a group of similar, yet different species. Although such terms serve a useful purpose for general identification, they do not acknowledge component parts and, therefore, perpetuate misunderstanding of specific characteristics. Are all snakes identical? Are all fibrous (asbestiform) minerals under the label "asbestos" likely to be identical? Where data exist, is the cause of good science served by not differentiating species and their respective attributes? "No" seems the logical response to each of these queries.

A summary follows of: 1) the nature of the problems related to the use of asbestos, 2) the world-wide geologic distribution of economic deposits of asbestos minerals, 3) the scope and significance of the asbestos industry, 4) highlights of asbestos in Arizona, and 5) health-related considerations. The term "asbestos" will be used in this article to denote the family of commercially exploited mineral fibers.



Part of a Quebec, Canada mining town nestled among waste piles resulting from the mining and milling of chrysotile asbestos. Photo from *Resources Quebec*, 1980, v. 4, no. 1, p. 18.

NATURE OF THE PROBLEM

As civilizations increase in complexity, the number of technical issues projected into the arena of public debate and reaction, especially in democratic societies, also increases. In those technical issues that are delivered to the body politic through the news media (a dominant form of public education), rhetoric may quickly overrun the information base or selectively use data to focus on a specific idea or perceived problem. In such cases, choosing between legitimate concern and overreaction, though difficult at best, seems an essential pursuit, if truth is to be sought rather than emotional response.

The projection of asbestos into the forefront of public awareness over the past decade stems from two conflicting factors: 1) asbestos, a naturally occurring group of earth materials used in a myriad of industrial and domestic products,

constitutes the base for an extensive, international mining, milling, and manufacturing industry, and 2) asbestos, under certain circumstances, is a contributing factor in the cause of cancer and other diseases. Thus, there is a diversity of interest in asbestos.

The lack of agreement on what constitutes an asbestos material is a continuing problem. Much disagreement exists over the definition of asbestos, especially as it pertains to occupational health and safety regulations. Defintions vary depending upon those concerned–medical interests, occupational health and safety enforcement agents, mineralogists, lawyers, industrial users, economists, etc. The occupational health and safety standards derive their definition from governmental agencies (U.S. Department of Health and Human Services, NIOSH-OSHA Work Group, 1980).*

The question before the world's health and regulatory establishments is the extent to which the hazards of asbestos outweigh the benefits. On this subject, the Office of Technical Assessment stated in 1981: "Because the Federal Government does not accept a threshhold level for carcinogens, a strict interpretation of these laws would require that risk be entirely eliminated." Obviously, this kind of interpretation creates a dilemma of large proportions. To what extent, as a practical matter, should such laws be enforced? Is there no room for flexibility? Actually, some flexibility is provided to regulatory agencies by Congress through the use of expressions like "unreasonable risks". However, who is to judge what constitutes a reasonable risk? The ideal is to balance risks, costs, and benefits, at the same time being sensitive to equity considerations (i.e., risks may be disproportionately borne by some in order to provide benefits for others).

Can a condition of reasonable risk be attained without debilitating the entire asbestos industry for all time? The answer to this question is encouraged by epidemiological data coming to light which indicate that chrysotile, the principal mineral of the asbestos industry, does not present the degree of risk that attends some of the other commercial fibrous materials.

MINERALOGY AND USAGE

Although there are many naturally occurring elongated minerals that are referred to variously as fibrous, asbestiform, acicular, filiform or prismatic, few occur in deposits suitable for commercial exploitation. Commercial asbestos is generally considered to occur naturally in six forms (see footnote on page 2). It is important to recognize that these six commercial fibrous minerals are not identical in crystal structure, chemical composition, abundance, geologic occurrence, degree of exploitation, etc. Furthermore, human epidemiological data (i.e., incidence, occurrence, and control of disease in a population) suggest that they also are not identical in their disease-causing potential. These commercial fiber types not only differ between species, but also somewhat within species as well. Differences exist in fiber dimension, flexibility, tensile strength, resistance to heat, electrical conductance, specific gravity, and other properties (Shride, 1969).

Each mineral locality tends to have its own set of fiber characteristics suitable for certain, but not all, possible uses. In other words, all occurrences of the same mineral species are not necessarily suited for identical uses. As examples, fiber length is a major factor in grading asbestos for commercial purposes–the longer lengths being more valuable, with the soft fibers worth more than harsh fibers. The longer fibers are valuable because they can be spun or woven into fabrics. Most of the spinning fibers are chrysotile asbestos. Amosite fibers are shorter and are used for various felted insulation products. Lighter weight products can be made with amosite for use in aircraft and ships. Crocidolite has high tensile strength and is acid resistant. Spun or woven crocidolite fibers are used in making fiber cement pipe because they allow free and rapid filtration of fluids that speeds up manufacturing processes (Bowles, 1959).

OCCURRENCE

Major sources of amphibole fibers have been the amosite and crocidolite deposits of South Africa, the crocidolite of western Australia, and the anthophyllite of East Finland (Ross, 1981). Minor occurrences of amphibole-type fibers in the U.S. that have had some production include anthophyllite in Georgia, North Carolina, Idaho, Maryland, and Massachusetts. Tremolite has been mined only in a small way from deposits in South Africa and Maryland. Commercial mining of actinolite is practically unknown. Today, mining of amphibole asbestos is essentially confined to South Africa.

By far, the most important commercial mineral fiber comes from the serpentine type known as *chrysotile*. The two most important world sources of this fiber are the Ural Mountains of Russia and the Appalachian Mountains portion of Quebec, Canada (Table 1), and northern Vermont, U.S.A.

Fiber Type	Continent/Source	Amount Produced
Chrysotile (5,317,000 MT)	Europe	2,775,000
	North America	1,713,000
	Africa	377,000
	Asia	293,000
	South America	101,000
	Australia	58,000
Crocidolite (210,000 MT)	Republic of So. Africa	210,000
Amosite (71,000 MT)	Republic of So. Africa	71,000
	World Total	5,598,000 MT

Table 1. Estimated world asbestos production by fiber type (metric tons), 1978 (data from U.S. Bureau of Mines).

Sixty years ago Arizona led the nation in the production of chrysotile. At that time Arizona chrysotile, formed about 1.2 billion years ago, contained about half as much iron as did the known Canadian (Quebec) chrysotile, a valuable asset

*At present, a widely used definition of asbestos in the United States is included in the proposed regulations and guidelines of "Occupational Exposure To Asbestos", published in the Federal Register by the Occupational Safety and Health Administration (OSHA). In this notice, the naturally occurring amphibole minerals (amosite, crocidolite, anthophyllite, tremolite, and actinolite) and the serpentine mineral (chrysotile) are classified as asbestos if the individual crystal fragments have the following dimensions: length greater than 5 micrometers (microns), maximum diameter less than 5 micrometers, and length-to-diameter ratio of 3 or greater. Any product containing any of these minerals in this size range is also defined as asbestos. [1 meter = 1,000,000 microns; 5 microns = .0002 inches].

A joint National Institute for Occupational Safety and Health and OSHA committee published the following in 1980: "Definition of Asbestos. Having considered the many factors involved in specifying which substances should be regulated as asbestos, the committee recommends the following definition: *Asbestos is defined to be chrysotile, crocidolite, and fibrous cumingtonite–grunerite, including amosite, fibrous tremolite, fibrous actinolite, and fibrous anthophyllite. The fibrosity of the above minerals is ascertained on a microscopic level with fibers defined to be particles with an aspect ratio of 3 to 1 or larger."*

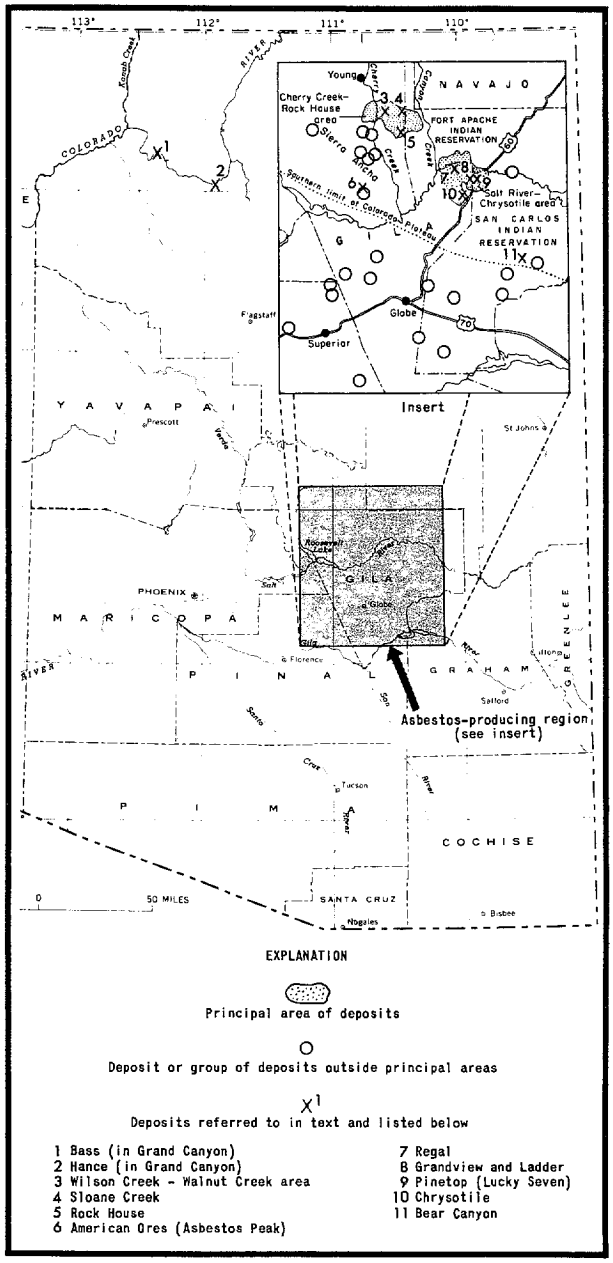


Figure 1. Map of major chrysotile asbestos occurrences in Arizona (from Arizona Bureau of Mines Bulletin 180).

for certain electrical applications. As recently as the 1950s, Arizona chrysotile was the only domestic source of low-iron chrysotile spinning fiber (used in covering electric cables) that met Navy asbestos specifications (Stewart, 1955). The filter market has been the principal outlet for high-grade Arizona chrysotile.

Chrysotile fiber is reported to have been seen in 1869 in the Grand Canyon by members of the Powell expedition (Wilson, 1928). Claims were filed about the year 1900 and a small amount of fiber was mined in 1903. The first of the more famous Gila County occurrences was recognized in 1872. However, additional discoveries were made and the first claims filed in 1913 (Stewart, 1955). In 1914 the Johns-Manville Company acquired the claims and soon became the leading producer in Arizona. Because of this early success, prospecting increased and hundreds of locations were made along the Salt River, Cherry Creek, and in the Sierra Ancha region of east-central Arizona. After World War I, the highest price for the best grade crude chrysotile reached $3,000 per ton, resulting in much early prospecting. In response to this early interest, the Arizona Bureau of Mines published a bulletin called *Asbestos* (Allen and Butler, 1921). Because of a continuing demand for information, another bulletin about Arizona asbestos followed (Wilson, 1928). Major Arizona occurrences of chrysotile asbestos are shown in Figure 1.

PRODUCTION

Although asbestos had been mined as far back as Roman times, the modern industry did not start until the late 1800s. By 1890 the asbestos industry was going strong, with hundreds of commercial applications for fibrous material. Northern Italy was the first region to come into production. However, by 1900 the large South African crocidolite deposits had been opened and the Russian deposits in the Ural Mountains were being mined in large quantity. A few years later, mining of amosite deposits of South Africa was initiated. By 1980 about 100 million MT (metric tons) of asbestos fiber had been mined throughout the world. More than 90 percent of this was chrysotile and about 5 percent amosite and crocidolite (Ross, 1982). The remaining few percent is attributed to the other amphibole fibers, principally anthophyllite.

Amosite from South Africa, crocidolite from Australia, and anthophyllite from East Finland all come from rocks about two billion years in age. South African fiber production presently amounts to about 200,000 MT per year. The production of Australian crocidolite was terminated in 1966 after 138,000 MT had been shipped. The anthophyllite deposits of East Finland were operated continuously between 1918 and 1975, when mining terminated for economic reasons; approximately 350,000 MT of fiber was produced, 230,000 MT of which was exported.

The Quebec chrysotile deposits were discovered in 1877. By 1900 Quebec had already supplied 150,000 MT of fiber; by 1980 nearly 40 million MT had been mined–approximately 40 percent of the world's total mineral fiber production (Ross, 1981). Russia is the world's largest producer of chrysotile today, the Ural area contributing about 2.4 million MT per year.

Other exploited chrysotile deposits are located in the Italian Alps (160,000 MT per year), Cyprus (40,000 MT per year), South Africa (113,000 MT in 1978), Swaziland (48,000 MT in 1978), Zimbabwe (210,000 MT in 1978), and in the Coalinga area of California. Although the California deposits include large near-surface reserves, mining has lagged because of short fiber length and environmental controls (Ross, 1981).

In 1978 Russia produced 2,582,000 MT of chrysotile fiber, 46.1 percent of the world's total fiber output. Canada produced 1,620,000 MT of chrysotile fiber, 28.9 percent of the world total. Thus, in 1978, 75 percent of the world's asbestos production came from just these two regions. In contrast, the U.S. produced 93,000 MT of fiber (chrysotile), less than 1.7 percent of the total. South African amosite and crocidolite production amounted to 281,000 MT or 5 percent of the world fiber output. The remaining 18.3 percent, all chrysotile, is attributed to 15 other countries, the largest shares assigned equally (3.7 percent) to China and Zimbabwe. Only three firms, operating in Vermont and California, are now producing asbestos (chrysotile) in the U.S. Table 1 shows the estimated world production for 1978.

Shride (1969) states that chrysotile asbestos was mined from about 160 deposits in Arizona and that perhaps another 60-70 occurrences are known. In terms of production, Arizona asbestos has, overall, been a small contributor. Shride estimates that total production through 1966 of at least 82,000 MT was valued at about $17 million at the time of sale. Today, the Arizona asbestos industry is inoperative.

CONSUMPTION

The following excerpts about the asbestos industry, as it once was, are taken from Bowles (1959):

> Asbestos furnishes a major raw material for a great variety of essential products, the manufacture of which constitutes a vast industry . . . the United States has developed the greatest asbestos-products industry in the world . . . Domestic mines furnish (in the form of chrysotile fiber) only 6-8 percent of all grades and an even smaller percentage of the important strategic grades.
>
> The procurement of necessary supplies is a problem of world-wide scope, and in every war emergency asbestos assumes top priority among strategic minerals. It is of paramount importance, therefore, that a thorough knowledge should be gained of the composition and properties of asbestos, its uses and requirements for each use, grades and specifications, the degree of essentiality of each application, the nature and extent of sources of supply throughout the world, mine and mill capacity, reserves, transportation, facilities, political and commercial control, world requirements by countries, import and export data, allocation of supplies, fiber beneficiation, possibilities of synthetic asbestos manufacture, use of substitute materials, past war controls, war history, and various other problems that may appear.

The U.S.S.R. has supplanted the United States as the largest consumer of asbestos fiber (Clifton, 1979). U.S. consumption for the years 1977-1982 is shown in Figure 2. Whereas the use of asbestos in developing countries is expanding, Figure 2 indicates a continuous decline in U.S. asbestos consumption since 1977. Clifton (1983) states that the 1982 domestic consumption of about 250,000 MT (over 90 percent supplied by Canada) is the lowest since 1940. He estimates that about 400 firms, centered in the eastern states, are manufacturing asbestos products. In 1982 U.S. commercial uses of fiber included asbestos-cement pipe (37 percent), flooring products (20 percent), friction products (14 percent), roofing products (9 percent), packing and gaskets (6 percent), asbestos-cement sheet (6 percent), and other uses (8 percent). Clifton also suggests that certain domestic market segments may have been permanently lost to substitutes. Although no wholly satisfactory substitutes are available for asbestos in many applications, such as friction needs, much research is underway to evaluate possible alternatives.

HEALTH HAZARDS

That asbestos fibers, under certain conditions of exposure, may cause disabling diseases in humans appears to be well established. Three principal diseases have been attributed to excessive exposure to asbestos fibers: 1) asbestosis, a fibrosis of the lung tissue which reduces the elasticity and function of the lungs, 2) lung cancer, and 3) mesothelioma, a rare cancer of the pleural and peritoneal membranes. Nearly all of the asbestos-related diseases have occurred in occupational groups—those concerned with mining and milling of asbestos, the manufacture of asbestos-containing products, and the application and removal of insulation materials containing asbestos fibers. However, some non-occupational asbestos-related disease has been documented and is summarized later.

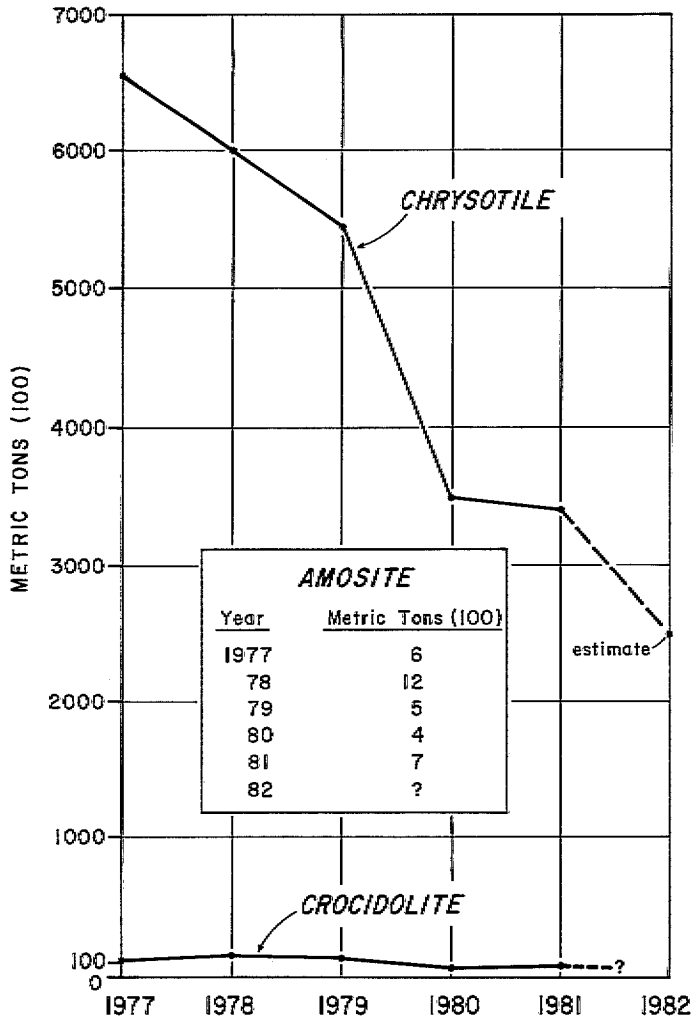


Figure 2. U.S. asbestos consumption by fiber type (100 metric tons), 1977-1982.

During the turn of the century when the use of asbestos fibers was increasing due to rapid expansion of product lines, the control of dust created by certain operations was not perfected. It is known that in some textile manufacturing operations, such as carding, spinning, and weaving of asbestos fibers, dust concentrations were so high that a person could not see beyond an arm's length. After many years of this type of exposure, some employees developed a pulmonary disease that was named asbestosis. Upon recognition of this affliction, dust control measures were initiated that significantly reduced the incidence of asbestosis.

The first suggestion of a causal relationship of exposure to asbestos fibers and lung cancer was proposed in the mid-1930s (Lynch and Smith, 1935). It was also recognized that there was a long time lag between first exposure and onset of disease. As with asbestosis, the control of exposure resulted in a marked decrease in the incidence of lung cancer.

The association of exposure to asbestos fibers and mesothelioma was not given serious consideration until after

1960 when 33 cases of mesothelial malignancies were reported in a crocidolite mining population in South Africa (Wagner and others, 1960). This disease appeared many years after initial exposure.

Generally, asbestos-related diseases appear in asbestos workers only after many years have elapsed since first exposure. A significant increase in the lung cancer death rate appears 10-14 years after first exposure and peaks at 30-35 years. The mesothelioma death rate becomes significant 20 years after first exposure, but continues to climb even after 45 years have elapsed. The asbestosis death rate becomes significant 15-20 years after first exposure and apparently peaks at 40-45 years (Selikoff and others, 1980). It is to be emphasized that these cited, generalized statistics are based upon studies of workers who were exposed daily to various fiber types as part of their work environment. The significance of exposure levels of the different fiber types, over time, needs to be addressed if precision and a guiding perspective are to be gained.

Risk

The determination of asbestos risk can be approached in two ways: 1) tests on animals, and 2) observations on humans exposed to asbestos dusts in mines and mills, and various plants and workplaces where these particular fibers are involved. The argument is made that animal studies are essential because the time required to study humans renders most direct studies impractical. The only reliable study of humans involves case histories with statistical data assemblages. A result is said to be positive when it reveals an excess of mortality that is caused by the agent under study. (An *excess* is that amount beyond what is statistically expected in a population not exposed to the risk.) Positive epidemiological results are taken by agencies as strong evidence of carcinogenicity, whereas a positive bioassay (animal test) is taken as evidence that a substance is a *potential* human carcinogen. Apparently, agencies specify stringent requirements with which to weigh negative epidemiological data against positive animal information.

Carcinogenicity of asbestos fibers has been studied by exposing laboratory animals to fibers by the following methods: intratracheal injection, intraperitoneal injection, intrapleural injection, ingestion, and inhalation. With the exception of inhalation, and ingestion to some extent, the foregoing routes of exposure are not likely in humans. In addition, the quantity of asbestos required to produce these effects in laboratory animals, by any of these routes of exposure, is high relative to dosages experienced by humans in occupational environments.

A report dealing with airborne asbestos was prepared by the Committee on Biological Effects of Atmospheric Pollutants (National Research Council, 1971), and information derived from their assessment of animal studies may be worth noting:

> Asbestotic pulmonary fibrosis has been produced experimentally in various species of animals, including rats, guinea pigs, hamsters, rabbits and monkeys. In many of the studies, the disease resembled early asbestotic development in man . . . Diffuse fibrosis has also been produced, but to do so it was necessary to use very high concentrations of asbestos dust and long periods of exposure or observation after exposure . . . Lung cancer from chrysotile dust has been produced experimentally in rats and in mouse lung implants. Other investigators who used different methods for introducing the dust did not find lung cancer in animals they studied... Rats whose lung clearance had been artifically impaired had twice the lung cancer rate of animals with normal clearance... cancer of the pleural surface (mesothelioma) has been reported in rats and hamsters that received intrapleural injections of the three most common types of asbestos. The amounts of asbestos dust introduced into the thoracic cavity were very large, and translation of results to human inhalation of asbestos is uncertain.

As already indicated, disease incidence increases significantly among various asbestos trades workers. Most of these are men who most likely handled several types of asbestos fibers during their working careers. In contrast, miners and millers tend to be exposed to only one form of fiber. This latter category, then, provides some opportunity to isolate the effects of individual fiber forms on health. More about this later.

Lungs of persons in urban and rural non-occupational settings have been shown to contain "asbestos" fibers. Many of these fibers, or bodies, are probably derived from the burning of leaves and from plant products, such as paper, wood, and coal, man-made fibers, talc used generously as a body dusting powder (which may contain tremolite), graphite, hornblende, diatomaceous earth and carborundum (National Research Council, 1971; Cooper, 1967). That thousands or even millions of fibers are present in most human lungs has been recognized since the turn of the century. Although many urban areas contain measurable asbestos fiber counts in the ambient air, epidemiological study indicates that there are no unusual health problems attributed to breathing chrysotile fiber in a non-occupational setting (Ross, 1982).

In many epidemiological studies, "asbestos" is the common denominator and specific fiber types are not considered. Some feel strongly that such lumping serves to mask the probability that the various fibers differ in their disease-causing tendencies in humans (Ross, 1982; Rutstein, 1982). This distinction, if valid, should be viewed with the knowledge that chrysotile fiber is the overwhelming contributor to asbestos production the world over, besides being the only fiber mined commercially in the U.S. However, amosite and crocidolite, though normally minor contributors, were heavily used in certain war-related industries during World War II.

Malcom Ross (1982), a physical chemist and geologist-mineralogist with the U.S. Geological Survey, has reviewed and analyzed asbestos-related data from 110 published sources from around the world. His primary interest was to survey asbestos-related disease in all aspects of the industry and assess *non-occupational* risks of fibrous minerals. Following are some of Ross' conclusions:

> 1) Non-occupational exposure to chrysotile asbestos, despite its wide dissemination in urban environments throughout the world, has been shown by epidemiological studies to be of no recognized health significance. If chrysotile asbestos were hazardous to health, the women of Thetford Mines, Quebec (where over 20 million MT of chrysotile asbestos has been mined), would be dying of asbestos-related diseases; yet this has not occurred (see cover photo). The health studies completed in Canada suggest that populations

can safely breathe air and drink water that contain significant amounts of chrysotile fiber.

2) Crocidolite asbestos shows an entirely different fiber-dose disease-response relationship from that observed for chrysotile asbestos. Health studies of those exposed only to crocidolite show that it is much more hazardous than chrysotile, perhaps 100-200 times more hazardous with respect to mesothelioma. The danger of crocidolite dust is particularly emphasized by the many mesothelioma deaths occurring among the residents of the crocidolite mining districts of the Cape Province, South Africa, where the exposure occurred in a non-occupational setting. Such mortality is practically unknown among residents of the chrysotile mining localities of Quebec. Control of crocidolite dust, particularly in mines and mills, presents a considerable engineering problem in that dust levels at or below the 1969 British Standard of 0.2 fibers/cm^3 (1 cm^3 = one cubic centimeter or one milliliter) virtually cannot be achieved (Simpson, 1979, p.74).

3) The hazards of amosite asbestos are more difficult to assess. The amosite factory employees of Paterson, New Jersey, who worked under very dusty conditions during World War II, have experienced excess mortality due to lung cancer, asbestosis, and mesothelioma. In contrast to these factory workers, amosite miners, and millers elsewhere in the world, at least with regard to mesothelioma, do not appear to be at much risk. This suggests that dust controls are possible which can greatly reduce or prevent the occurrences of asbestos-related diseases in amosite workers.

4) The fear caused by statements and implications to the effect that "one fiber can kill" and by the apparently exaggerated predictions of the amount of asbestos-related mortality expected in the next 20 or 30 years, has generated much political pressure to remove asbestos from our environment and to greatly reduce or even stop its use. An example of this is the concerted effort in several industrial nations, including the United States, to remove asbestos from schools, public buildings, homes, ships, appliances, etc. This is being done, even though most asbestos in the U.S. is of the chrysotile variety, and even though asbestos dust levels in schools, public buildings, and city streets are much lower than dust levels found in chrysotile mining communities where no asbestos-related disease has been reported in the non-occupationally exposed residents. The impetus for these costly removals and appliance recalls (hair dryers, for example) apparently comes from capitalizing on the "one fiber can kill" concept. Not only is this program costly–it could be dangerous if the removal of crocidolite asbestos is not accomplished with great care. In most cases, asbestos coatings and insulation, where necessary, can be repaired at no risk and at a fraction of the cost of complete removal.

Rutstein (1982) comments on relative health hazards of the various fiber types:

> Outside the U.S., particularly in Great Britain, it is widely believed that crocidolite is much more dangerous than chrysotile, and, further, that much of the data suggesting that asbestos is harmful is based on the effects of crocidolite, and perhaps, amosite, but not on the much more widespread chrysotile . . . Let us now consider why there was an asbestos scare. Irving Selikoff of the Mount Sinai School of Medicine continues to lead in advocating the dangers of asbestos. His classic studies (1973) of the asbestos-insulation workers of New Jersey show quite clearly that they were indeed much more susceptible to asbestosis and various cancers. Lung cancer was prevalent, especially if the workers smoked cigarettes. Most of the asbestos workers in Selikoff's studies were probably exposed to more than just the chrysotile variety of asbestos. Crocidolite was particularly favored for insulation on ships. However, the interpretation of the epidemiological data did not stress distinguishing between health effects attributable to different mineral species, but only to "asbestos".

Why should these fiber types act differently? Perhaps because they have contrasting physical and chemical attributes. For instance, chrysotile fibers curl into spirals, whereas the amphiboles (crocidolite and amosite) develop straighter, more needle-like fibers, and appear to penetrate more deeply into the terminal air sacs of the lungs (Figure 3). Chrysotile is a magnesium silicate, amosite is an iron-magnesium silicate, and crocidolite is a sodium-iron-magnesium silicate. Their solubilities and resistance to chemicals are known to differ.

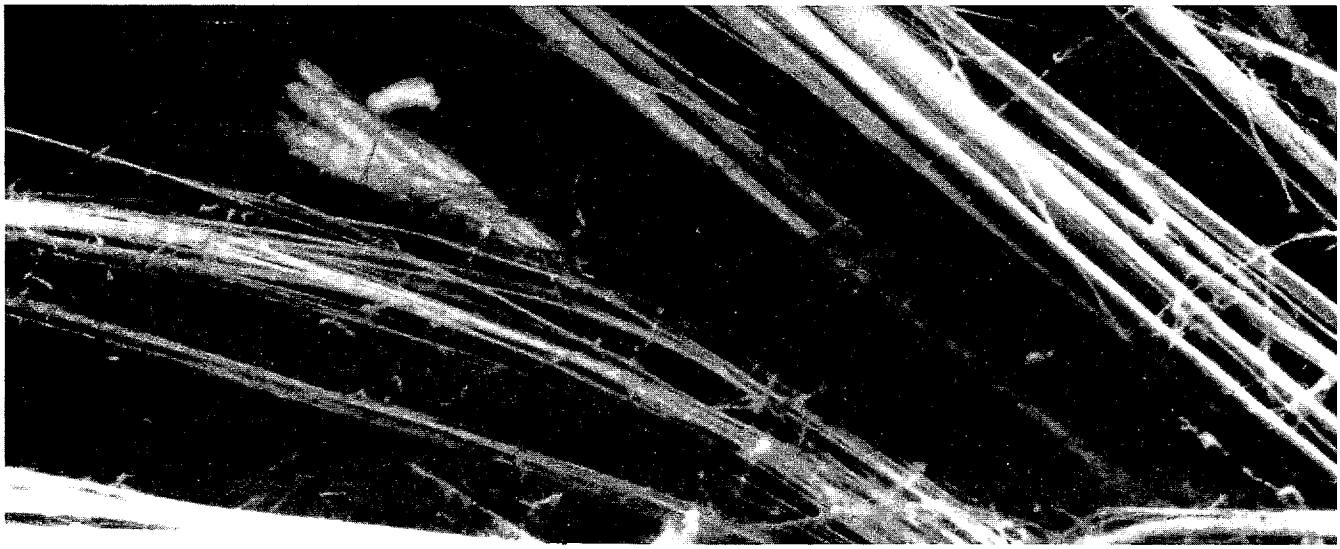
Recently, the authors attended a talk (January 21, 1983) about asbestos-related disease, presented by Margaret Becklake, M.D. (McGill University, Canada) at the University of Arizona medical center. She restated her belief that chrysotile eventually dissolves in the lungs and therefore does not continue to accumulate like the amphibole fibers do. Previously, she had reported the following (Becklake, 1982):

> Subsequent studies have also strengthened the evidence that fibers dissolve out of the lungs over time, the loss occurring preferentially in chrysotile fibers. Thus, though chrysotile accounts for the bulk of commercial use and hence human exposure, it is the amphiboles that constitute the core of the majority of asbestos bodies found in human lungs, even in those known to have had occupational exposure to chrysotile (Warnock, 1979; 1980; 1981) . . . All these findings strengthen the evidence that chrysotile is cleared more readily from the lungs than other fibers . . .

Perhaps the best available information on chrysotile fiber exposure-risk levels comes from studies in Canada, the source of much of the chrysotile fiber used in the U.S. As an example, Ross (1982) reports:

> Epidemiological studies of the chrysotile asbestos miners and millers of Quebec, undertaken by medical researchers in Canada, show that for 3,105 men exposed for more than 20 years to chrysotile dust averaging 20 fibers/cm^3, the total mortality was less than expected (620 observed deaths, compared to 659 expected deaths). Risk to lung cancer was slightly increased–48 deaths observed and 42 deaths expected. Exposures to 20 fibers/cm^3 are an order of magnitude greater than those experienced now (generally less than 2 fibers/cm^3); thus chrysotile miners working a lifetime under these present dust levels should not be expected to suffer any measurable excess cancer.

How much is 20 fibers/cm^3? According to Rutstein, at an allowable limit of 2 fibers/cm^3 of air (over an 8-hour industrial environment workday), the average worker could easily inhale 7 million fibers per day. Thus, he too questions the incon-



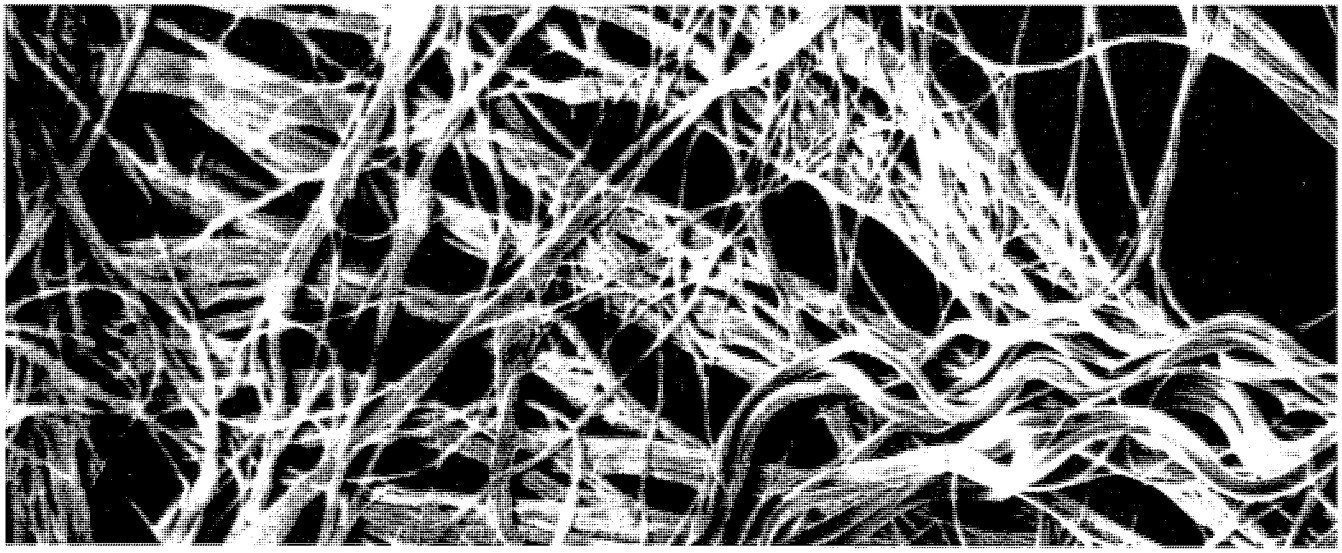


Figure 3. Crocidolite (straight fibers) from South Africa and chrysotile (wavy fibers) from Globe, Arizona, viewed through a scanning electron microscope. The thinner fibers are less than .0004 inches thick. Photos courtesy of the U.S. Geological Survey.

sistency revealed in permitting the inhalation of several million fibers on the one hand and promoting the "one fiber can kill" concept on the other hand.

Clifton (1983) reports that the United Kingdom Health and Safety Commission decided to implement tighter controls over asbestos exposure. The new limits, which were effective January 1, 1983, are: chrysotile, one fiber per milliliter of air (1 f/ml); amosite, 0.5 f/ml; and crocidolite, 0.2 f/ml. [chrysotile was lowered by 1 f/ml and the others are unchanged.]

What is known of the asbestos-related mortality rate in the U.S. and what are the estimates for the future? If one looks over the data, it becomes obvious that firm numbers do not exist. Ross points out that former Secretary of the U.S. Department of Health, Education and Welfare, Joseph A. Califano, reported figures in a 1978 speech that translate into 76,000 cancer deaths per year due to asbestos. The data came from medical scientists associated with the National Institutes of Health. In 1980, Dr. Irving Selikoff stated at a press conference that 20,000 U.S. asbestos workers would die each year for the next 40 years of "excess disease". Subsequently, in 1981 Dr. Selikoff, through a press release to the Associated Press, stated that 10,000 American workers are dying each year because of asbestos exposure. He did not supply a data source for these estimates.

Ross asks if any of these numbers are correct. Using existing statistics from Vital Statistics of the United States dealing with mortality factors, asbestosis deaths in the nation for the period 1967-1977 are seen to average 41 per year. However, Ross cites data indicating that deaths due to this cause are underreported, therefore adjusts the average figure to 88. Using this number in combination with asbestos-related epidemiological statistics, Ross estimates the likely annual mortality due to lung cancer and mesothelioma. Combining these, his estimates for total annual asbestos-related mortality range from 522-587. Furthermore, he thinks that asbestos-related mortality will peak between 1980 and 1985, 35 to 40 years after the large World War II shipyard employment.

In regard to the estimation of risk in human non-occupational exposure to asbestos, the National Research Council's

Committee on Biological Effects of Atmospheric Pollutants (1971) wrote:

> The most important question in the case of persons with non-occupational exposures to asbestos is whether there is an increased risk of malignancies. Industrial experience indicates that there is no likelihood of significant asbestosis in non-occupational exposure. The major potential for risk appears to lie in those with indirect occupational contacts, household contacts, or residence in the immediate neighborhood of asbestos sources; and even there, the actual risk is poorly defined. But the fact that there appears to be a gradient of effect in such groups suggests that there are levels of inhaled asbestos without detectable risk. It is not known what range of respirable airborne asbestos fibers will ultimately be found to have no measurable effects on health. At present, there is no evidence that the small numbers of fibers found in most members of the general population affect health or longevity.

More recently, in response to a question concerning non-occupational exposure to chrysotile asbestos in Canada (see cover photo), Dr. Becklake stated the following (personal communication, 1983): "A mortality study has been carried out referring to residents of the asbestos mining towns of Quebec. No significant excess general mortality was shown in women. The excess in men was thought to be related to occupational exposure." Asked if society should ban all forms of asbestos use, Dr. Becklake commented, "We humans live with many dangerous materials and are able to control others; why not this one?"

Globe, Arizona, has been in the news periodically, most recently because of its association with EPA's Superfund. A mobile home park is situated on land, parts of which were once dedicated to the processing of chrysotile asbestos. At question is the health risk. A dilemma prevails because there are no factual scientific data that clearly define the relationship between all possible exposure levels of chrysotile asbestos and risk. As already pointed out, high *occupational* exposure levels can be risky, whereas there is no evidence of significant risk at levels frequently characterized as *non-occupational*. However, how should the possible exposure levels at the mobile home park be characterized? Might they be high, low or intermediate, depending upon several variables? Is living there likely to be more or less hazardous than living in the chrysotile mining and milling centers of Quebec, Canada? Because of a paucity of accurate, scientific data, and in spite of efforts to gather more, answers to such questions remain largely subjective and somewhat arbitrary. Although this is the nature of the problem that confronts the various state and federal agencies, decisions must nevertheless be made. In the absence of definitive, scientific health-risk data, decisions on final actions will inevitably be based upon economic-political considerations.

Substitutes

In a report of the Advisory Committee on Asbestos, Health and Safety Commission of Great Britain, the following statement is made regarding substitutes for asbestos (Simpson, 1979, v.1, p.69):

> As a general principle we take the view that control of any useful but hazardous material is preferable to the ultimate sanction of prohibition. It is very easy to say that a dangerous substance or process should be banned and to hope that that will solve the problem. In our view, this is a gross over-simplification of a complex equation of interlinked factors. It ignores the possibility that prohibition of a particular substance may directly result in an increase in health or safety risks, for example from fire, which the use of that substance currently prevents or reduces. It also ignores the implications of statutorily enforcing substitution by materials or substances that presently appear to be suitable but may at a later date be found to constitute a risk to health. The social and economic consequences of the possible closure of factories using the original material or process need be taken into account.

Until recently, the U.S. has been the largest producer of asbestos products, mostly from imported fiber. The three principal natural fibers that enter into commerce–crocidolite, amosite, and chrysotile–have physical and chemical characteristics that are difficult to duplicate by substitution. As a consequence, substitutes tend to perform in an inferior way. The costs (including health and safety), imposed on society because of inferior performance, are not yet known.

CONCLUSIONS

The mining, milling, processing, and fabrication of a family of naturally occurring fibrous asbestos minerals, especially chrysotile, is world-wide in scope. The overall benefits of asbestos products to society at large are incalculable. Because of adverse publicity, the "hazards" of asbestos seem to preclude benefits derived from its use.

The specter of disease, especially cancer, has been attached by some to the exploitation, processing, use, and even general occurrence of asbestos. How serious is the asbestos-related disease threat? Judging from the data cited in this perspective-seeking report, the hazard seems to depend principally on two points: 1) the specific mineral, and 2) exposure level.

The nature of the asbestos problem is recognized and it is believed that present technology is capable of controlling occupational chrysotile exposures to levels that are not anticipated to result in excess disease. Studies of the non-occupational health risk of chrysotile suggest no detectable excess disease; therefore, the prevailing generalization that *any* non-zero exposure to chrysotile can cause serious medical problems should be questioned.

These data, though not finally definitive, nevertheless support the contention that failure to discriminate between the various fiber types and exposure levels is scientifically and practically inappropriate. Thus chrysotile may have become the victim of "guilt by association", having been lumped with the more dangerous minerals, crocidolite and amosite, under the general term, "asbestos".

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ERRATA

Two figures in the Technical Report prepared by Reynolds and Keith, *Geochemistry and Mineral Potential of Peraluminous Granitoids* (December 1982, v. 12, no. 4, p. 5), were mislabeled. Figures 1 and 3, reprinted below, have been corrected. The positions of the labels "alkaline" and "subalkaline" have been reversed, as shown here.

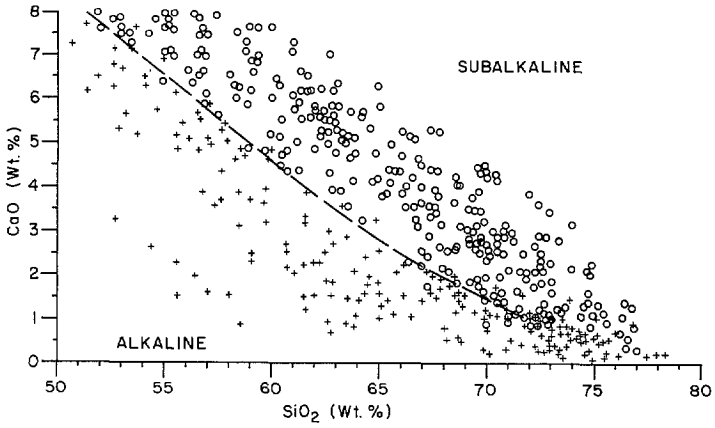

Figure 1. SiO_2 versus CaO variation diagram for metaluminous-suite igneous rocks of known alkalinity. Dots represent calc-alkalic and calcic rocks; crosses indicate alkali-calcic and alkalic rocks (classifications according to Peacock, 1931).

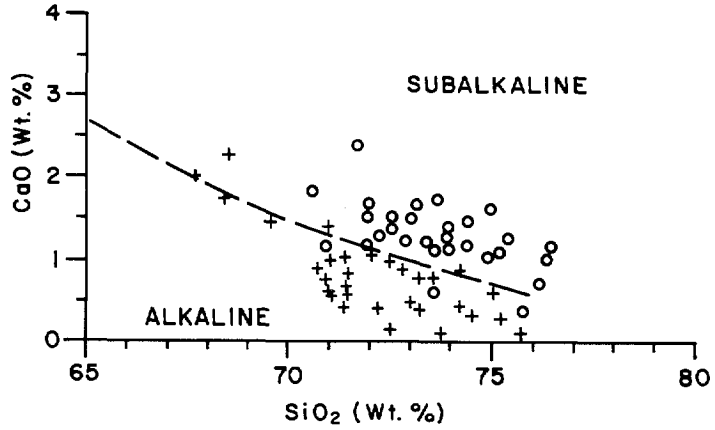

Figure 3. SiO_2 versus CaO variation diagram for peraluminous granitoids of Arizona (o) and the Hercynian belt of Europe (+).

NEW PUBLICATIONS

Roadside Geology of Arizona, by Halka Chronic; Mountain Press Publishing Co. (Box 2399, Missoula, MT 59806; 406/728-1900), 1983, 314 p. Aspects of Arizona's geology and diverse landscapes that can be seen from the highways are presented in this "guidebook" as an introduction to those with little or no geologic training. $9.95

Checklist of Arizona Minerals, by Raymond W. Grant, Mineralogical Society of America (PO Box 902, Phoenix, AZ 85001), 1982, 78 p. Describes physical properties of 640 known minerals in Arizona; lists the state's minerals according to Dana's system. ($6 + shipping) $7.00

ARIZONA MINERAL PRODUCTION FOR 1981

by Jon E. Spencer

Arizona maintained its standing as the leading copper producer in the U.S., producing almost 68 percent of total U.S. copper production. Copper output reached 1,040 thousand metric tons, surpassing the previous high record achieved in 1979. See Table 1 for copper-mine production in Arizona.

Pima County, Arizona's number one copper-producing county, produced more than three times as much copper as the state of Utah, the second largest copper-producing state. Arizona ranked second in molybdenum and silver production, and fourth in gold production. These metals were recovered primarily as byproducts of copper production (See Table 2).

1981 RANK	1980 RANK	MINE	COUNTY	OPERATOR
1	1	Morenci	Greenlee	Phelps Dodge Corp.
2	5	San Manuel	Pinal	Magma Copper Co.
3	4	Ray Pit	Pinal	Kennecott Copper Corp.
4	3	Twin Buttes	Pima	Anamax Mining Co.
5	7	Pinto Valley	Gila	Cities Service Co.
6	2	Sierrita	Pima	Duval Corp.
7	6	Bagdad	Yavapai	Cyprus Bagdad Copper Co.
8	8	Inspiration	Gila	Inspiration Consolidated Copper Co.
9	9	Eisenhower	Pima	Eisenhower Mining Co.
10	13	Magma (Superior)	Pinal	Magma Copper Co.
11	10	Pima	Pima	Cyprus Pima Mining Co.
12	11	New Cornelia	Pima	Phelps Dodge Corp.
13	—	Mission	Pima	ASARCO Inc.
14	—	Silver Bell	Pima	ASARCO Inc.
15	15	Sacaton Unit	Pinal	ASARCO Inc.

Table 1. Leading copper-producing mines in Arizona, in order of output

Detailed statistics on Arizona nonfuel mineral production have been recently published in the Arizona chapter of the U.S. Bureau of Mines' *Minerals Yearbook* for 1981. Additional information can be obtained from Lorraine Burgin, State Minerals Specialist for Arizona, with the U.S. Bureau of Mines in Denver.

MINERAL	1980 QUANTITY	1980 VALUE (thousands)	1981 QUANTITY	1981 VALUE
Copper (metric tons)	770,119	$1,738,908	1,040,813	$1,953,142
Molybdenum (thousand pounds)	35,668	341,965	35,808	254,345
Sand and Gravel (thousand short tons)	24,399	73,773	22,679	169,855
Silver (thousand troy ounces)	6,268	129,363	8,055	84,728
Gold (troy ounces)	79,631	48,779	100,339	46,120
Lime (thousand short tons)	514	23,904	538	29,913
Stone–crushed (thousand short tons)	6,205	24,780	6,315	26,263
Gem stones	—	3,100	—	3,250
Gypsum	209	2,017	213	2,594
Clays (thousand short tons)	151	1,151	148	1,105
Lead (metric tons)	165	152	993	800
Pumice (thousand short tons)	9	13	1	3
Combined value of asbestos, barite (1981), cement, perlite, pyrites, salt, tungsten, and vanadium	—	83,037	—	93,009

Table 2. Production and value of metallic and non-metallic minerals in Arizona

(data from U.S. Bureau of Mines' *Mineral Yearbook*, 1981)

Arizona Surpasses U.S.S.R. in Copper Production

Arizona is a copper producer of international significance. Statistics from the copper chapter of the Bureau of Mines' *Minerals Yearbook* for 1981 indicate that Chile was the only nation that produced more copper than Arizona (Figure 1). Only five nations–Chile, the Soviet Union, Canada, Zambia, and Zaire–produced more copper than Pima County (Figure 2). Due largely to Arizona's copper output, the United States was the world's number one copper producer, with total production in 1981 of 1,538 thousand metric tons.

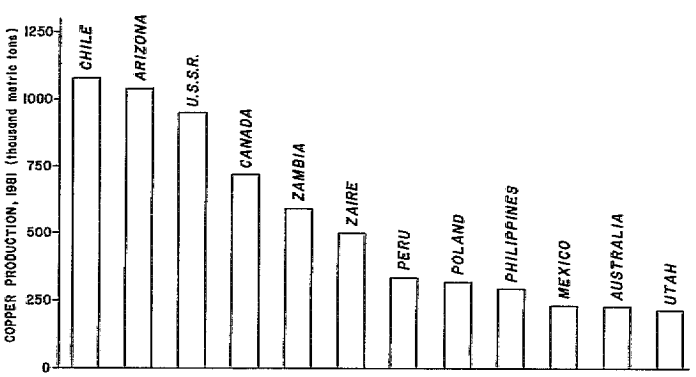

Figure 1. Copper Production in 1981: States and Foreign Countries.

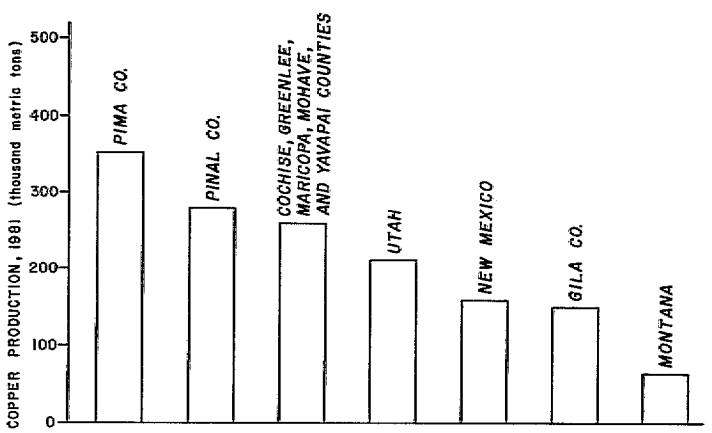

Figure 2. Copper Production in 1981: Arizona Counties and Other States

BUREAU PUBLICATIONS

Geothermal Energy in Arizona, a report prepared by Claudia Stone and James C. Witcher, has been placed on open file at the Arizona Bureau of Geology and Mineral Technology.

This is the final report on work done by the Bureau under contract with the U.S. Department of Energy, Division of Geothermal Energy (Contract No. DE-FC07-79ID12009), between May 1977 and August 1982.

The report brings together in a single volume current knowledge of and basic data on potential geothermal resources in Arizona. In addition it includes results of preliminary investigations for each area of the State in which geothermal assessment was made.

Most of the geothermal waters that have been identified in Arizona are in the low (less than 90° C) to moderate (90°–150° C) temperature range. The most likely potential uses for waters in this temperature range are for direct-heat (nonelectric) applications such as space heating and cooling, agriculture and aquaculture production, and industrial processes.

Open-File Report 83-12, "Geothermal Energy in Arizona", may be examined at the Arizona Bureau of Geology and Mineral Technology library. Copies are also available for purchase for $20.00 (over-the-counter) or $24.00 (by mail order). Make checks payable to the Bureau of Geology and Mineral Technology, 845 N. Park, Tucson, AZ 85719. Payment must accompany mail order request.

NOTICE

Response to the State Geologic Map of Arizona (1969) was so great that the Bureau's stock has been depleted. More maps have been requested from the U.S. Geological Survey, which is currently arranging for the reprint. The Bureau of Geology and Mineral Technology will announce in a later issue of *Fieldnotes* when the state map will again be available for purchase.

ANNOUNCEMENTS

Cartographers, illustrators, drafters, and researchers — consider revising your county base maps of Arizona. "La Paz" (meaning 'peace') is the state's newest county, in the area which was formerly northern Yuma County. Specs may be obtained by writing the Yuma County Courthouse at 168 S. 2nd Ave., Yuma, AZ 85364.

The Department of Interior has awarded ten contracts to eight contractors for the collection of data on foreign mineral deposits. The data will include name, ownership, and location of each deposit; ore tonnage and grade figures; a description of the orebody and extraction system; staffing and energy requirements; and a detailed cost analysis. An extensive data base on the availability of minerals will emerge as the Minerals Availability System (MAS) is implemented.

One of the contractors is located in Tucson, AZ — Pincock, Allen & Holt, Inc.; the firm has been awarded $179,836 for the study of beryllium, lithium, zirconium, mercury, and molybdenum deposits.

Arizona Oil & Gas Conservation Commission

1982 Activity Report *A.K. Doss, Executive Director*

Another busy year for oil and gas exploration and related activities in Arizona has concluded. Two of the wildcats were "near misses" and one other wildcat logged oil and gas shows that were good enough to result in a very expensive attempt to complete the hole as a producer. The following table indicates a comparison of activities for the last 3 years.

	1980	1981	1982
1. Number of drilling permits issued	14	73	48
2. Total number of wells drilled	8	51	42
3. Total footage drilled	32,775	65,400	76,708
4. Number of dry holes	7	9	16
5. Number of oil producers	0	6	1

As can be seen there were fewer wells drilled in 1982, but the amount of footage drilled was considerably more than in 1981. Numbers 4 and 5 above show that there were substantially more wildcats drilled in 1982 (17) and more than double the number (7) drilled in 1980. The predicted 100,000 feet drilled for 1982 was not reached; this was undoubtedly the result of budget cutbacks in practically all the oil companies. The ratio of producers to dry holes should improve measurably for 1983 because Kerr-McGee plans to drill seven infill wells in the Dineh-bi-Keyah field and Mountain States plans additional drilling in the Teec Nos Pos field. The one producing well was drilled by Mountain States as their #12 Navajo-0, a stepout in the Teec Nos Pos field.

Brooks Exploration drilled a 7,000-foot wildcat in the strip country about halfway between Fredonia and Colorado City (Short Creek). They ran a drill stem test (DST) between 570 feet and 642 feet and recovered 70 feet of oil-cut mud and 20 feet of free oil. The oil was analyzed as 29° gravity API. The oil formation is tentatively identified as the Schnabkaib member of the Moenkopi Formation. Follow-up drilling could result in a field discovery similar to the old Virgin field type just across the state line in Utah. The other "near miss" is the Gustin #1-24 Federal, located one mile north of Chambers. This well has sweet gas and oil on the pits at approximately 1,358 feet (formation unidentified). The oil on the pits was a high-gravity sweet crude. The operator has installed a small pumping unit and, at last report, was pumping water. Follow-up drilling is planned around this well.

Fifteen geothermal gradient holes were drilled by Phillips Geothermal Division in the Agua Caliente and Alpine areas. These holes accounted for about 6,000 feet of drilling.

At the present time, the following estimated amounts of acreage are under active oil and gas leases: 1) Federal 10,500,000 acres; 2) State 2,500,000 acres; and 3) Private 5,000,000 acres.

Oil and Gas Revenues to Arizona

1. Advalorum taxes (10¢/$ on gross sales of oil and gas)	$1,300,000
2. Sales tax (2% of the gross sales of oil and gas)	400,000
3. Rentals to the state (state lands and one-half on federal lands	8,000,000
4. Commercial sales (rent, food, clothing, fuel, trucking charges, recreation, etc.), conservatively estimated	600,000
Total Revenues	$10,300,000

The prognosis for 1983 is that of another year of continued high drilling and exploration activity and an improved possibility of finding the first discovery of oil and gas off the Indian Reservation.

Arizona Bureau of Geology and Mineral Technology Annual Report for 1982

The Arizona Bureau of Geology and Mineral Technology, known as the Arizona Bureau of Mines until 1977, consists of a Geological Survey Branch and a Mineral Technology Branch. The Geological Survey Branch is the state geological survey. The Bureau is administered by the Arizona Board of Regents and is supervised by the President of the University of Arizona or his designate, traditionally the Dean of the College of Mines.

The Bureau is defined by statute as a scientific, investigative, and information agency whose purpose is to do research and provide information about the geologic setting, mineral and energy resources, mineral technology, and the impact of "things geologic" in Arizona. Information and research projects and activities during 1982 are summarized below.

INFORMATION AND ASSISTANCE. Information and assistance are provided by Bureau scientists, upon request, to the legislature, governmental agencies, industry, and the public. In addition, the Bureau publishes, sells, and distributes geologic maps and reports; maintains a library that contains published and unpublished maps and reports; maintains a repository of rock cuttings and cores, and publishes a quarterly newsletter, *Fieldnotes*.

Bureau staff commonly work with staff members of other state agencies, including the Land Department, Oil and Gas Conservation Commission, Department of Mineral Resources, Department of Transportation, Department of Health Services, Department of Water Resources, Office of Economic Planning and Development, Energy Office, and others.

RESEARCH AND DATA COLLECTION. Projects completed during 1982:

1) *Geothermal Resources Map of Arizona*, 1:500,000 scale, published as Map 15;
2) *Index of Published Geologic Maps, 1903-1982*, 6 sheets at 1:1,000,000 scale, published as Map 17;
3) *Geothermal Resources in Arizona, A Bibliography*, published as Circular 23;
4) *Arizona Earthquakes, 1776-1980*, published as Bulletin 193;
5) *Geologic Map of the South Mountains*, 1:24,000 scale;
6) *Geologic Map of Western Harquahala Mountains*, 1:12,000 scale;
7) *Quaternary Geologic Map of Arizona*, 1:250,000 scale;
8) Entry of mineral production and occurrence data for Arizona into Computerized Resource Information Bank (CRIB);
9) Geologic data compilation and assessment of mineral potential in selected wilderness study areas in Safford district (Bureau of Land Management).

Projects in Progress: 1) map showing mineralized districts in Arizona, 1:1,000,000 scale; 2) report on the geology of South Mountains; 3) outcrop map of rocks of Laramide age, 1:1,000,000 scale; 4) report on geologic occurrence of uranium in Arizona; 5) map of Quaternary faults in Arizona, 1:500,000 scale; 6) map of late Cenozoic faults and volcanic deposits, 1:500,000 scale; 7) geologic maps of Phoenix, Tucson, and Nogales on 1° × 2° sheets, 1:250,000 scale; 8) report and map on the geology and mineral resources of Little Harquahala and Granite Wash Mountains; 9) geochemistry and mineral potential of granitic rocks in Arizona; 10) map showing geologic hazards in Arizona, 1:1,000,000 scale; 11) bibliography of geologic hazards in Arizona; 12) final report on potential geothermal resources in Arizona; 13) teachers resource guide for environmental education manual; 14) runoff processes in southeastern Arizona; and 15) geology and hydrology of the Basin and Range province in Arizona (a series of rock type, tectonic, mineral resource, and hydrologic maps and report).

A number of the projects listed above were done under contract with federal agencies, including the U.S. Geological Survey, Department of Energy, Nuclear Regulatory Commission and Bureau of Land Management.

Fieldnotes

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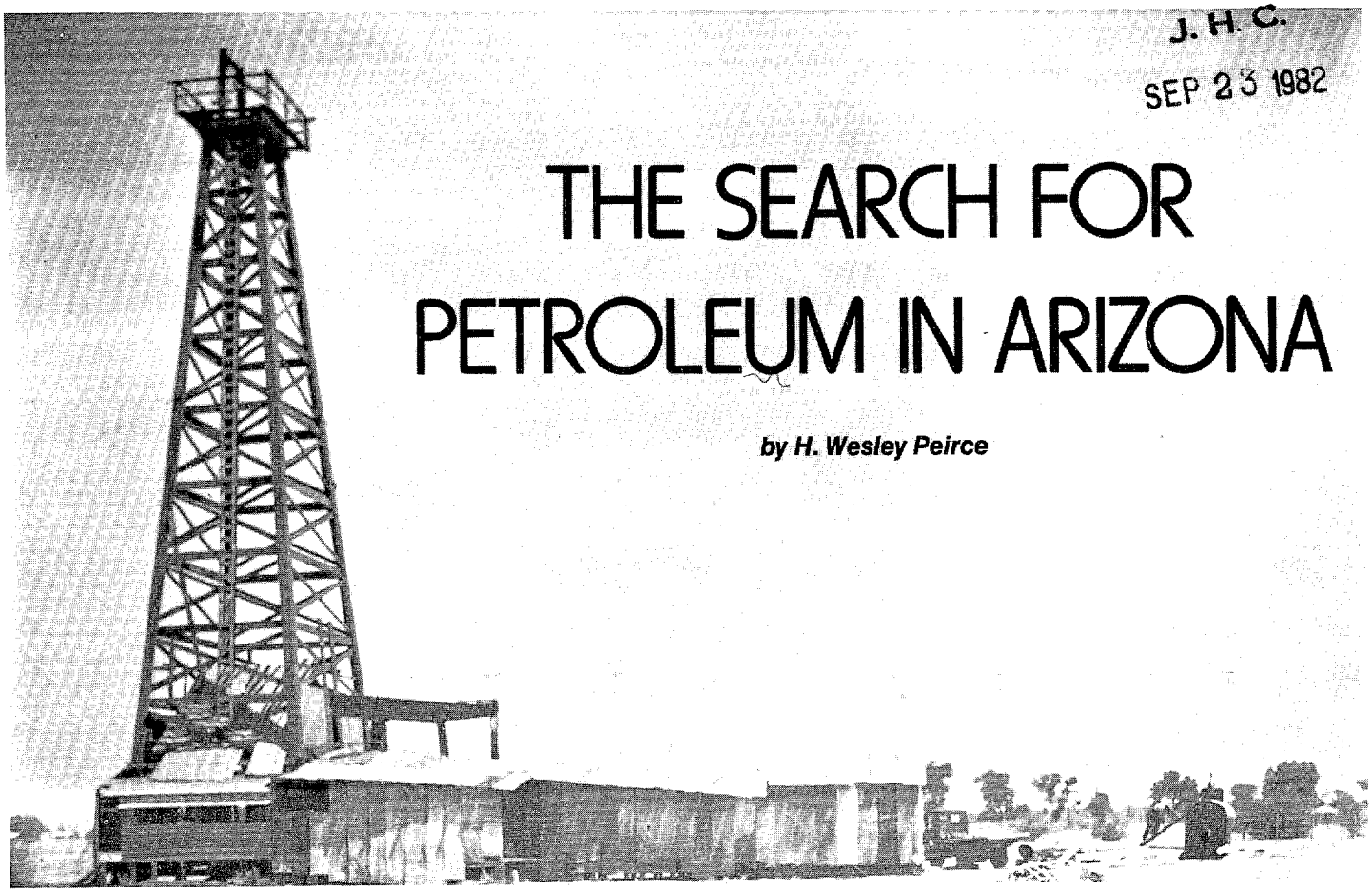
J. H. C.
SEP 23 1982

THE SEARCH FOR PETROLEUM IN ARIZONA

by H. Wesley Peirce



Phoenix drilling venture. Hole located between 24th and 32nd St., north of Van Buren and east of State Hospital. Hole abandoned at 1,600 feet due to lack of funds (1939). Photo: Elvin E. White.

INTRODUCTION

Although E. L. Drake drilled the first oil well in western Pennsylvania in 1859, it wasn't until the turn of the century that the incessant search for oil started. It began with the development of the internal combustion engine and the arrival of the age of gasoline. With the drilling of an oil exploration test hole in 1903, Arizona territory became a part of the search terrain. Subsequently, a relatively low-level, spasmodic exploration effort has continued within the state (Figure 1). Some of the highlights of this search, and associated discoveries, are reviewed here.

It is often said that the search for petroleum (crude oil and natural gas) begins in the mind, that drilling is the culmination of the search and not the beginning. Because ideas often go unrecorded, the most tangible, recoverable record of petroleum exploration is the drillhole. An idea may result from either a casual effort or a lengthy process of sophisticated geologic investigation, and the mere existence of a drillhole suggests little about the thought behind its placement and depth. Ideas change through time as

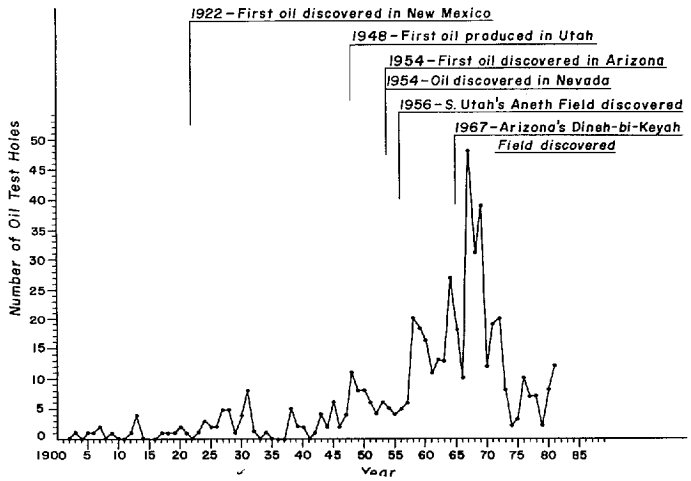


Figure 1. Number of oil test holes per year. Data from the Arizona Bureau of Mines Bulletin 182.

geologic understanding evolves. Exploration and drilling techniques also change, and these activities are becoming increasingly expensive, necessitating a judgment as to how much effort can be supported by available financial resources. In this regard, the price of petroleum products has a major influence on incentive. The search for petroleum is a costly, high-risk venture and easily discourages the pessimistic and the timid. The old adage "nothing ventured nothing gained" certainly applies to the business of discovering significant petroleum resources.

Although the physical record of holes drilled in Arizona, in the pursuit of petroleum resources is very good, the reasoning behind the placement and depth of each hole is often obscure, especially when reviewed at a later date. At the time of drilling, rumors tend to be rampant and care is required if, during later assessment, truth is to be separated from fiction. Frequently, a hole is drilled and, for technical or financial reasons, is abandoned short of its intended objective. In such cases the original idea is not tested, even though a hole was drilled. Thus, because a hole has been drilled, is not in itself sufficient reason to reject reevaluation of the petroleum potential of the same area. Reevaluation is an unending, constant process among the petroleum hunters.

The following comments about the search for petroleum in Arizona are very general and cannot do justice to the thought, effort, time, and money that have been invested over the last 79 years in attempts to find petroleum within the state.

GEOLOGIC PROVINCES

The state of Arizona consists of almost equal parts of two major U.S. physiographic provinces: 1) Colorado Plateau to the northeast, and 2) the Basin and Range country to the southwest (Figure 2). Actually, the dividing line between the two provinces is the northwest-trending, 300-mile-long Mogollon Rim that bisects the state. Although traditionally referred to as physiographic provinces, they are, fundamentally, geologic provinces. Their respective geologic characteristics are as different as night and day, and these differences are manifested in a diversity of ways,contrasting rock types, geologic structures, and known natural resources, including petroleum. Utilizing current knowledge, it is reasonable to state that: 1) the Colorado Plateau province holds most of the state's energy resources (oil, gas, coal, uranium), and 2) the Basin and Range province contains the state's metallic mineral deposits (copper, molybdenum, gold, silver, lead, zinc, etc.), and over 93 percent of the state's population.

FUNDAMENTALS OF PETROLEUM OCCURRENCE

The prevailing scientific wisdom is that petroleum is formed in sedimentary environments that contain abundant organic matter capable of being transformed into petroleum. Once formed, petroleum fluids must accumulate in large amounts if they are eventually to be exploited by wells. Oil and gas (being fluids) move, under the influence of pressure gradients, through rocks via natural plumbing systems. Such migration can lead to dispersion and loss or to concentration in some type of geologic trap. Often, the trap is a domal structure which is detectable at the earth's surface or in the deep subsurface by geophysical techniques. Most of the surface structures have been drilled, but it is the elusive 'blind' subsurface structures that are presently being sought. The search is more costly than ever and tends to discourage the "little guy."

Although petroleum is believed to have been derived from sedimentary rocks, it can, after migration, collect in any rock type having appropriate physical properties, especially open space. This fact complicates the search in geologically complex regions because exotic occurrences are very difficult to find.

THE SEARCH IN ARIZONA

Records indicate that the first oil exploration hole in Arizona (before statehood) was drilled to a depth of 2,003 feet in Chino Valley (Yavapai County), north of Prescott in 1903. Many of the early holes were drilled by promoters who raised capital by the

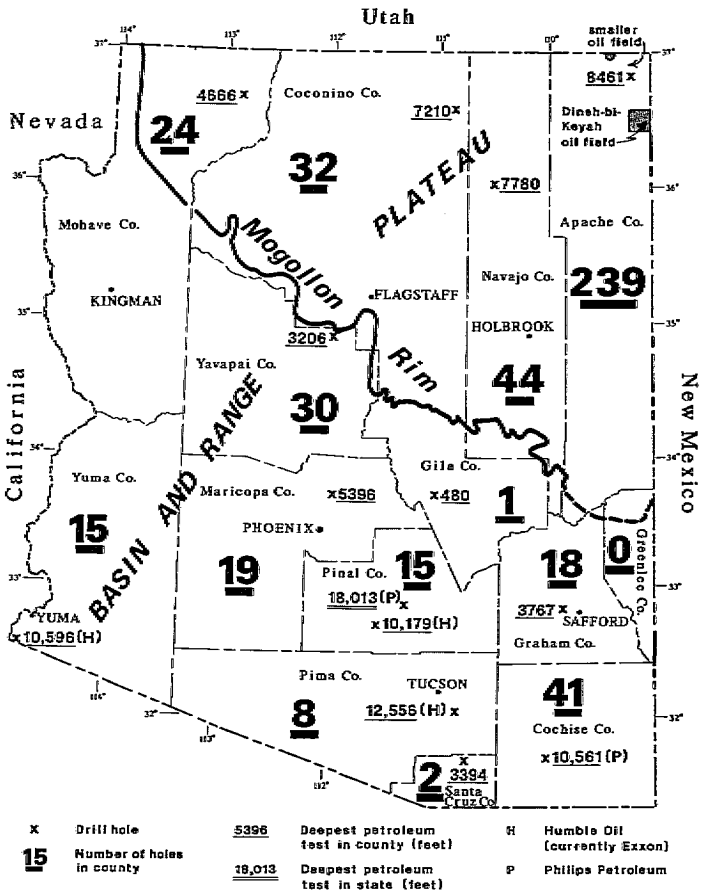


Figure 2. Map showing number of petroleum tests by county; deepest test in each county and state; oil producing region.

sale of interests. Although promotion is sometimes given a negative connotation, very often it is the only way for individuals and small companies to raise money for risky ventures.

About 488 petroleum tests and development wells have been drilled in Arizona to date (Figure 2). Sixty-five of these, or approximately 13 percent, have resulted in some oil production. Natural gas has been found only in relatively small quantities. All oil production has come from a tiny part of northeastern Arizona on the Navajo Indian Reservation where tribal policy controls all exploration ventures (Figure 2). The policy has been to have a lease sale on high-interest lands so that drilling rights go to the highest bidder, a procedure that limits participation to relatively well-financed companies. Lesser entities generally find it necessary to explore on non-tribal lands, a restriction that affects the search for petroleum in Arizona, in that it significantly reduces the chance for "accidental" discovery. (There is still an element of luck behind most mineral and energy resource discoveries).

More than 120 exploration holes were drilled in the state before the first oil find in 1954 by Shell Oil Co. (Figure 1). The resulting field, the Boundary Butte field, is small and adjacent to the border with Utah. Additional small fields were developed in the Arizona portion of the Four Corners region. Then, in 1967, Kerr-McGee drilled their discovery hole in the Dineh-bi-Keyah field (Navajo name for "peoples' field") (Figures 1–4). A total of 33 productive wells have been completed in this unusual oil field. It is unusual in that the reservoir rock is igneous. The wells are situated atop the Lukachukai Mountains among pine trees at elevations of 7,000–8,000 feet (Figure 3). The productive horizon is less than 3,000 feet below the surface.

By the end of 1981, 18,113,666 barrels of oil had been produced in Arizona, 16,141,285 barrels* (89 percent) of which was from

*Data from the AZ Oil and Gas Conservation Commission (1981).

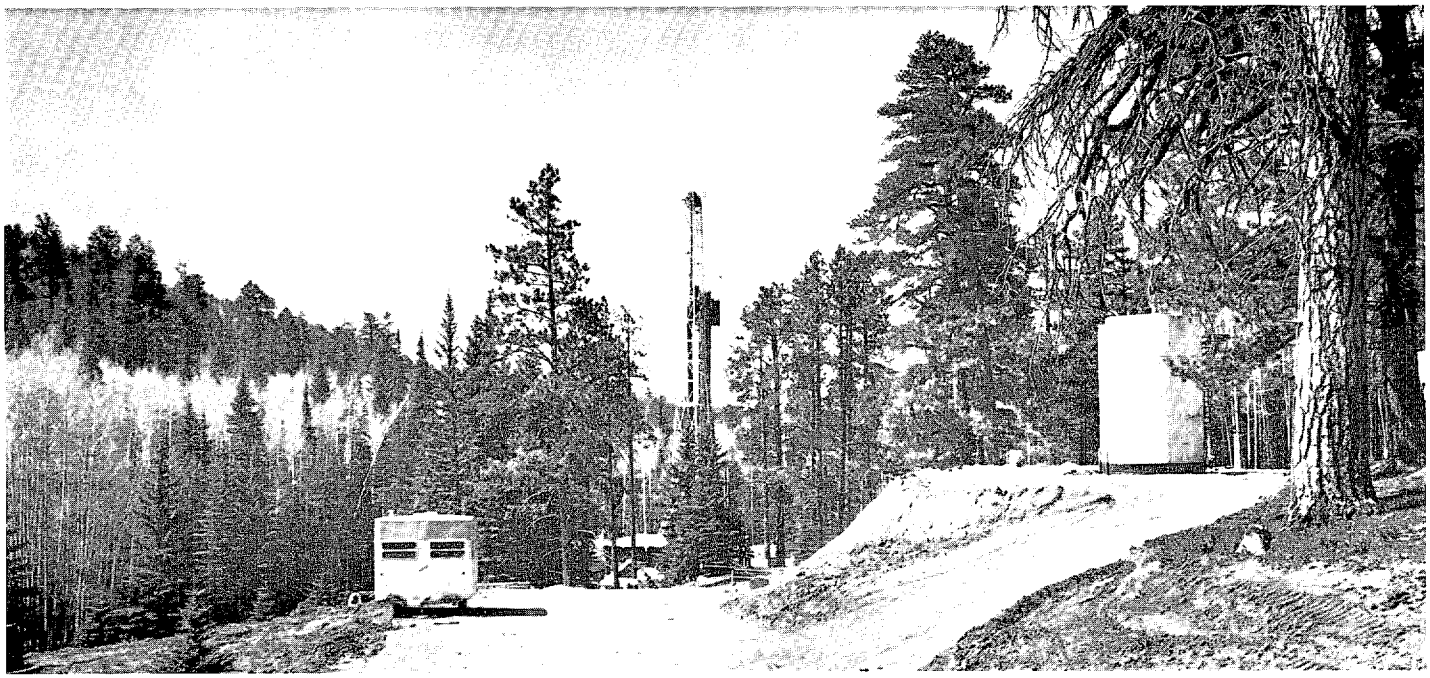


Figure 3. Drilling in Dineh-bi-Keyah field, Navajo Indian Reservation, Arizona (1968). Photo: H. Wesley Peirce.

Dineh-bi-Keyah (Figure 5). Thus the state production curve, shown in Figure 5, largely reflects the production from this field. Oil fields naturally decline in production, as is illustrated in Figure 5. The production high point was reached in 1968 at over three million barrels; by 1981 production was down to 357 thousand barrels per year, a ten-fold decrease. The state's proven reserves are dwindling because there has been no significant production from new discoveries. The national trend is similar in that oil is being pumped at a faster rate than it is being replaced through discovery of new sources.

As previously noted, oil production is restricted to a small portion of northeastern Arizona adjacent to Four Corners. There has been less drilling and no production from the southwestern half of the state, i.e., the Basin and Range portion.

It has been emphasized that Arizona's geologic framework is one of major contrasts. The Colorado Plateau to the northeast, in three dimensions, is dominated by sedimentary rocks that are but slightly deformed by folding and faulting, and range in thickness between zero and about 9,000 feet. Under these circumstances, if petroleum ever existed in the buried strata, its chance for preservation is excellent. However, Arizona's Basin and Range country to the south is characterized by a complex sequence of rock units that have been severely faulted, folded, and subjected to elevated temperatures. Under these circumstances, even if oil survived the various structural and thermal events, points of concentration would be difficult to anticipate. Consequently, it is the Plateau that has received the largest share of attention and, thus far, contains the only known crude oil reserves in Arizona and only small amounts of natural gas.

The three- dimensional geologic framework of Arizona's Plateau region varies significantly from place to place, in accordance with variations in geologic history and associated processes (see Reynolds, 1982). The end result is a spectrum of oil potential that ranges from nearly impossible to good. One of the guiding principles in petroleum exploration has been to stay away from areas with an igneous history. Ironically, Arizona's largest oil field, Dineh-bi-Keyah, as already noted, has an igneous rock as a reservoir. However, circumstances surrounding this occurrence are not well understood. The problem is one of petroleum migration timing.

Most of the oil potential of northern Arizona is related to about 4,000 feet of Paleozoic-age strata (230–570 m.y. ago). Although

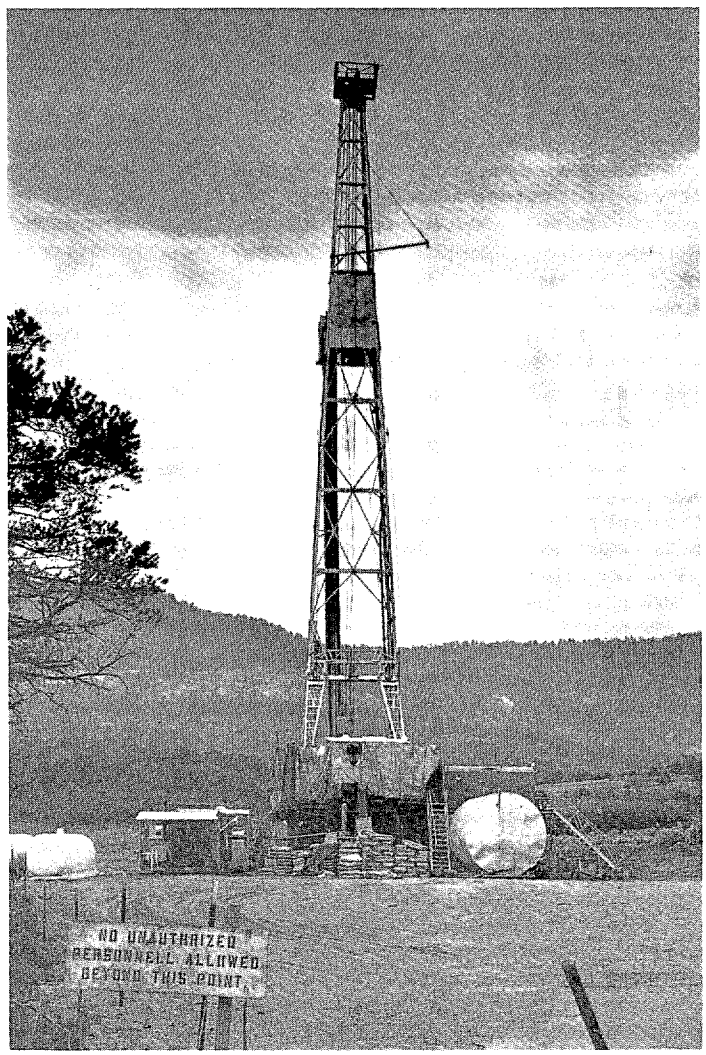


Figure 4. Close-up of drill rig (1968), Dineh-bi-Keyah field, Navajo Indian Reservation, Arizona (note sign, lower left corner). Photo: H. Wesley Peirce.

the walls of the Grand Canyon consist of sedimentary rocks of this age, significant lateral changes in rock character take place away from it. For example, although the specific source-rocks in the Four Corners region are Paleozoic in age, they do not extend into the Grand Canyon. This is easily explained by the fact that the particular sea involved in source-rock accumulation did not cover the Grand Canyon region. Also, the canyon itself is a negative factor in petroleum preservation because, not only does it allow a region of indefinite size to be drained of any hydrocarbon fluids, it also lowers subsurface pressures over a much larger region than it occupies.

The sea that produced the source rocks for the Four Corners country covered just a small portion of extreme northeastern Arizona and it is this part that is reponsible for most of Arizona's petroleum production. However, other marine rocks do occur, as in the Holbrook region to the south, and they provide some petroleum potential away from the Four Corners area. In recent years the leasing activity in the Holbrook country has picked up.

Whereas much of the Colorado Plateau country is a rather conventional setting in which to search for oil, the Basin and Range province of southern Arizona is "frontier" all the way. This province is ore-deposit country where past igneous activity, structural deformation, and elevated rock temperatures were relatively commonplace. As a consequence, the geologic literature on southern Arizona is dominated by the observations of geologists who specialized in the search for ore deposits, not oil pools. Observations of rock characteristics of critical importance to petroleum geologists were often not made. This has led to another evaluation phase of the fundamental geologic history as it might apply to the generation, storage, and preservation of crude oil and associated natural gas. Some research techniques developed by the petroleum industry have only recently been applied to southern Arizona. One of these assesses the maturity of organic matter contained in sedimentary rocks.

Organic matter, in order to generate oil and/or natural gas, must be subjected to appropriate temperatures. Natural gas is generated at higher temperatures than is crude oil. Many petroleum geologists think that southern Arizona subsurface thermal regimes have been so high that natural gas is more likely to occur than oil. However, there are others who think that because temperatures were so high, the likelihood of preserving either oil or natural gas is minimal. This may be true for petroleum that is related to rocks affected by a particular thermal event, of which there have been several in southern Arizona. What about rocks that post-date most of the severe thermal activity?

It was this line of thinking that brought Humble Oil and Refining Co. (now Exxon) into southern Arizona in 1971. The Basin and Range province takes its name from the present topographic appearance of alternating ranges and valleys. Knowledge then available indicated that valleys were often underlain by thick sequences of relatively young and diverse strata. However, little was known about the nature of these rocks at depth. The question of marine vs. non-marine was not critical because the famous oil shales of Colorado are non-marine in origin. Such rocks would

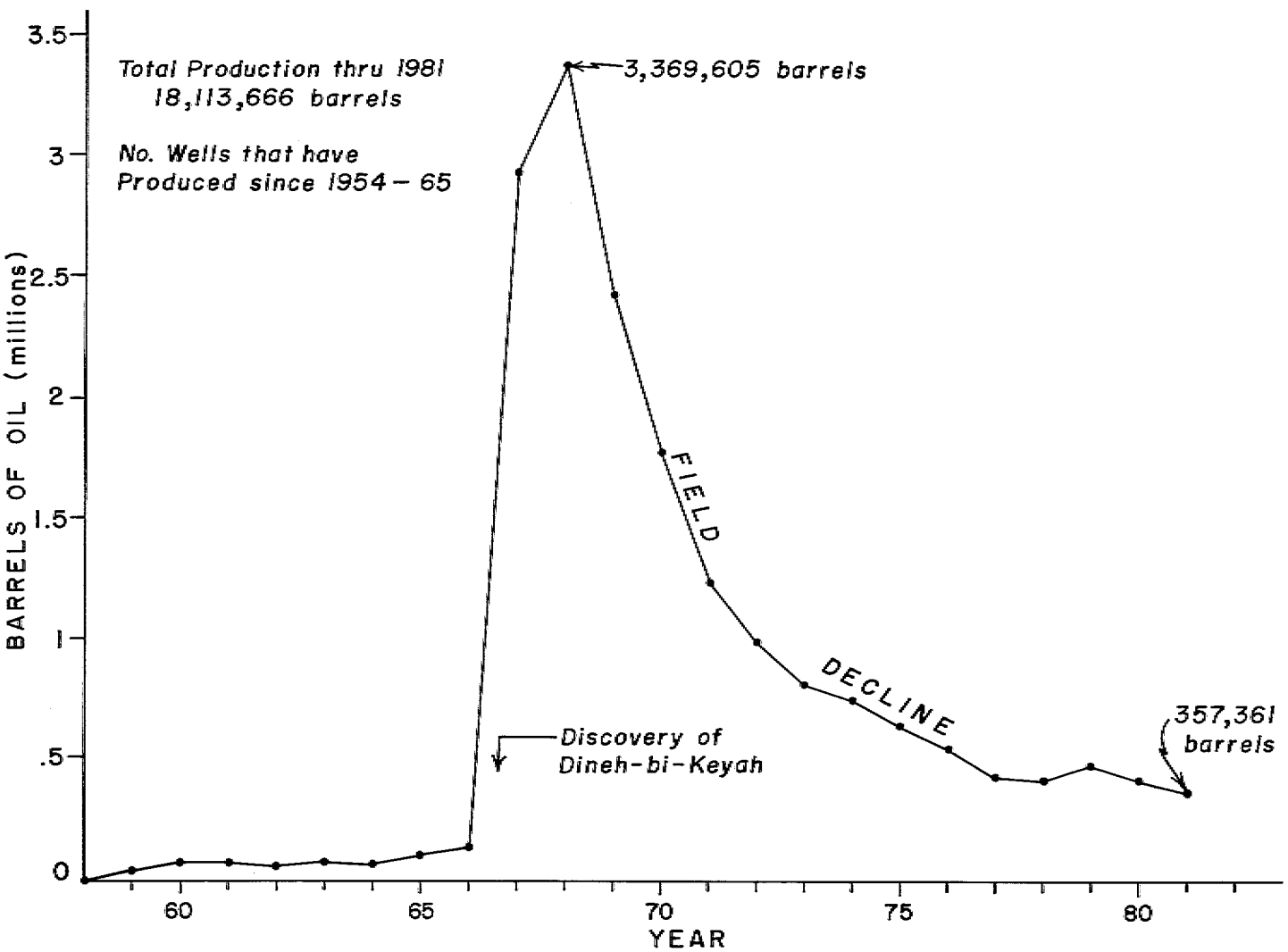


Figure 5. Annual oil production in Arizona (1953–1981). Data from the Arizona Oil and Gas Conservation Commission.

serve as adequate sources but not reservoirs. The size of some of the basins also indicated that volumes of contained sediment could be enough to generate significant amounts of petroleum, providing that the original environments of sediment accumulation afforded sufficient organic matter from which hydrocarbons could be generated. In addition, there was the possibility that certain other hydrocarbon-rich rocks, young enough to have escaped severe thermal disruption, could underlie the deeper parts of the valleys. Such rocks are known in several southern Arizona ranges, including the Tucson Mountains near Tucson. Humble drilled four holes totaling 36,850 feet, after leasing much of an 18,000-square-mile swath of Arizona desert (from Mexico to California) and conducting surface geologic studies and seismic surveys designed to provide information on rock arrangements at depth. Although this effort provided much information about how Arizona is put together, no significant petroleum was encountered. This project was bold, imaginative, and theoretically sound. It demonstrated that even though the young sediments were thick (on the order of thousands of feet), they were not organic-rich, at least where drilled (Figure 2).

After the Humble effort, interest waned in the Arizona Basin and Range province. Then, in 1978, another idea invaded the media—the concept of an "overthrust belt" through southern Arizona. Again, almost all leaseable land was picked up, especially inexpensive state lands. The overthrust hypothesis, as espoused by the principals in this promotion, was presented in *Fieldnotes* (Keith, 1980). It held, in part, that about 60 million years ago, older granitic rock that now characterizes a northwest-southeast-trending belt (including Phoenix and Tucson) through the Basin and Range province, was shoved (thrust) over younger, possibly oil-related strata. Certain seismic patterns were interpreted to represent sedimentary rocks having a domal form at depth, beneath granitic rocks known to be at or near the earth's surface. The only way to test the idea was to drill.

Late in 1980, what was destined to become the deepest probe to date into Arizona's mysterious region of "down" was started. Several months and about 12 million dollars later, the exploration test was terminated at 18,013 feet. Below the granite, layered sedimentary rocks were not encountered, only other igneous and metamorphic rocks. The seismic reflections proved to be a response to the internal characteristics and structures associated with these rock types. Three major rock bodies were encountered, and the interpretation of their relationships and significance has been discussed (Reif and Robinson, 1981). The final geologic significance of this test will remain in doubt until more is learned about the complexities of crystalline rock (granitic and metamorphic) geology in southern Arizona. The data from this hole remain equivocal as to the presence or absence of significant thrusting. It is a problem in interpretation.

Related to this "overthrust" venture is a hole near Tombstone drilled to about 10,000 feet by the same interests that drilled the Florence hole—Phillips Petroleum Co., Anschutz Corp., and Peoples' Energy. Engineering problems apparently caused premature abandonment, thus rendering the test inconclusive. Although geologic analysis of this test has yet to be released, some information is available. The hole was terminated in sedimentary rocks of suspected Cretaceous age, at a depth of 10,561 feet. Older rocks are believed to occur higher in the hole, suggesting that faulting has placed these older rocks (granite and limestone) over the younger rocks. The nature of the faulting has yet to be evaluated. Phillips Petroleum is planning to drill at least six additional holes designed to gather basic geologic information in southern Arizona; three of these are completed, two are being drilled, and one is planned.

Thus far, southern Arizona continues to be ore-deposit country, not petroleum. Petroleum very likely existed here prior to a series of disruptive geological events that may have dispersed much preexistent oil and/or natural gas. Some petroleum could remain, perhaps in highly unusual places, but finding it is proving elusive and costly.

Meanwhile, periodic drilling takes place in the Plateau country. Most recently, activity has centered north of the Grand Canyon near the Utah-Arizona boundary. Here, known oil seeps are constant reminders that hydrocarbons have been around. However, many of these are from surface rocks not sufficiently buried to contain oil of high fluidity and under sufficient pressure to make them flow and concentrate in traps.

Arizona possesses oil in its Plateau country, and most likely, there is more to be found. On the other hand, the southern Arizona Basin and Range country continues to be a scientific "frontier" and is not giving up its secrets easily.

An extensive overthrust zone is known to exist from Alaska to Mexico. However, its continuity is broken from place to place; one of the larger breaks involves most of southern Arizona where geologic complexity obscures the clear delineation of such a zone, if one ever existed. Intense exploration for petroleum in the western overthrust belt, since 1975, has resulted in substantial discoveries in the Wyoming-Utah region. This play was extended to Arizona where advantage was taken of relatively low-cost leases, especially on state-owned lands. This activity spawned renewed interest in southern Arizona and resulted in an intensive reexamination of its basic geologic framework. Although the information gained is invaluable and will be applicable in diverse ways for years to come, the case for petroleum occurrence in the Basin and Range province of Arizona seems not to have been enhanced. However, there is much more to learn than is presently known about the region. A good idea could lead to another flurry of exploration activity. The search goes on.

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GRAVITY MAPS

The Complete Residual Bouguer Gravity Anomaly Map has been completed in two scales. The 1:250,000-scale, two milligal contour interval map was produced by Dr. C.L.V. Aiken of the University of Texas (Dallas), under contract to the Geothermal Group of the Bureau of Geology and Mineral Technology (DOE contract #DE-FC07-79ID12009). This map is open filed at the Bureau (Report #81-24) and may be copied through local blueprint services. (Contact blueprint company directly for pickup, delivery and payment). The 1:500,000-scale map, prepared by Joseph C. Lysonski, C.L.V. Aiken, and John S. Sumner, is available from the Geophysical Society at the Department of Geosciences, University of Arizona for $25.00 (blue or blackline print).

HYDROLOGIC STUDIES IN ARIZONA

by Michael R. Long **Supervisor, Basic Data Unit**
Arizona Department of Water Resources

The Arizona Department of Water Resources (ADWR) and the U.S. Geological Survey (USGS), through a cooperative agreement, are responsible for hydrologic data collection for the State of Arizona. The data collection efforts include two programs—surface water and ground water.

The surface water data collection program is designed to monitor streamflow quantity and quality and includes operation and maintenance of more than 200 gaging stations on streams and rivers throughout Arizona. The ADWR shares the costs of 65 of these stations with the USGS. The remaining gaging stations are maintained through similar agreements between USGS and other state, county, and federal agencies.

Stream gage data are gathered to provide current and long-term streamflow data, used in the planning and management of storage reservoirs and the forecasting of floods. Streamflow data are used by the managing agencies responsible for storage reservoir operation (e.g., Salt River Project and San Carlos Irrigation District) to maintain the maximum storage possible along the major river systems in Arizona. In addition, 41 of the gaging stations are equipped with satellite telemetering equipment to provide data for flood forecasting. The ADWR and USGS have also cooperated in establishing a direct readout ground station in Phoenix, making flood flow data available more quickly and improving Arizona's flood warning capabilities. The data gathered in the surface water program are published in the USGS report series, "Water Resources Data for Arizona."

The ground-water data collection program includes three elements: 1) annual statewide ground-water monitoring program, 2) ground-water basin study program, and 3) research of specific hydrologic problems. The ADWR and USGS share the cost of these studies.

The statewide monitoring program is operated by the USGS and includes measuring water levels in selected monitoring wells and gathering ground-water pumpage data throughout the state. The data collected for the annual monitoring program are published annually, in map form, in a USGS open-file report titled, "Annual Summary of Ground-Water Conditions in Arizona."

The ground-water basin studies, formerly conducted by the USGS, have been conducted by the ADWR since 1979. These studies include comprehensive investigation of selected Arizona ground-water basins on a rotating basis. Data are collected in each basin every five to eight years to provide an overview of ground-water conditions of each basin. The comprehensive investigations include well site inventories for all major production wells, and water-level measurements and water-quality analyses in selected wells. The data collected in the ground-water basin

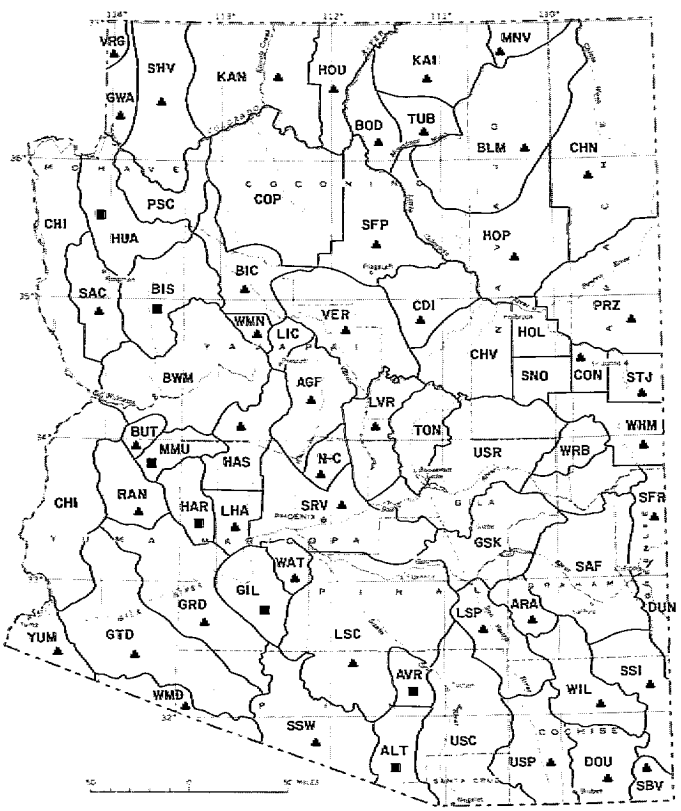

Figure 1. Map of areas investigated in Arizona.

■ Report published by the Arizona Department of Water Resources

▲ Report published by the U.S. Geological Survey

Blank indicates report not yet published

AREAS AND ABBREVIATIONS

AGF—Agua Fria basin
ALT—Altar Valley
ARA—Aravaipa Valley
AVR—Avra Valley
BIC—Big Chino Valley
BIS—Big Sandy Valley
BWM—Bill Williams
BLM—Black Mesa
BRB—Black River basin
BOD—Bodaway Mesa
BUT—Butler Valley
CDI—Canyon Diablo
CHV—Chevelon
CHN—Chinle
COP—Coconino Plateau
CHI—Colorado River (Hoover Dam to Imperial Dam)
CON—Concho
DOU—Douglas basin
DUN—Duncan basin
GIL—Gila Bend basin
GRD—Gila River drainage (Painted Rock Dam to Texas Hill)
GSK—Gila River (head of San Carlos Reservoir to Kelvin)
GTD—Gila River (Texas Hill to Dome)
GWA—Grand Wash
HAR—Harquahala Plains
HAS—Hassayampa basin
HOL—Holbrook
HOP—Hopi
HOU—House Rock
HUA—Hualupai Valley
KAI—Kaibito
KAN—Kanab
LIC—Little Chino Valley
LHA—Lower Hassayampa
LSP—Lower San Pedro basin
LSC—Lower Santa Cruz basin
LVR—Lower Verde River
MMU—McMullen Valley
MNV—Monument Valley
N-C—New River-Cave Creek
PSC—Peach Spring Canyon
PRZ—Puerco-Zuni
RAN—Ranegras Plain
SAC—Sacramento Valley
SAF—Safford basin
SRV—Salt River Valley
SBV—San Bernardino Valley
SFP—San Francisco Peaks
SFR—San Francisco River basin
SSI—San Simon basin
SSW—San Simon Wash
SHV—Shivwits
SNO—Snowflake
STJ—Saint Johns
TON—Tonto basin
TUB—Tuba City
USR—Upper Salt River basin
USP—Upper San Pedro basin
USC—Upper Santa Cruz basin
VER—Upper Verde River
VRG—Virgin River
WAT—Waterman Wash
WMD—Western Mexican drainage
WHM—White Mountains
WRB—White River basin
WIL—Willcox basin
WMN—Williamson Valley
YUM—Yuma

studies are currently published in the ADWR report series, "Hydrologic Map Series Reports." Previously, the data were published in the USGS open-file report series, "Water Resources Investigations." Six reports have been published as Hydrologic Map Series reports and 45 basin study reports have been published as Water Resources Investigation reports since the program began. The most recent example is a report entitled, "Maps Showing Ground-Water Conditions in the McMullen Valley Area, Maricopa, Yavapai, and Yuma Counties, Arizona."

ADWR staff are currently studying the Little Chino Valley (LIC), Waterman Wash area (WAT), Lower Hassayampa area (LHA), the Upper Santa Cruz area (USC), Avra and Altar Valleys (AVR/ALT), and the Salt River Valley (SRV).

Research on specific hydrologic problems is conducted by the USGS and ADWR. The research includes site-specific studies and interpretive analysis of hydrologically complex areas of the state. The research may include geologic mapping, well inventory, detailed water-level data collection, detailed water-quality monitoring, digital ground-water modeling, geophysical investigations, and exploration drilling programs. The results of the research and the data collected are published in the ADWR bulletin series. To date, eleven bulletins have been published; most were published as Arizona Water Commission (AWC) bulletins (AWC was ADWR's predecessor). The latest report in this series is entitled "Water Resources in the Sedona Area, Yavapai and Coconino Counties, Arizona."

For information on ADWR publications, contact the Arizona Department of Water Resources, Basic Data Unit, 2810 South 24th Street, Suite 122, Phoenix, Arizona 85034. For information on USGS publications, contact the U.S. Geological Survey, Federal Building, 301 West Congress, Tucson, Arizona 85701.

NEW STAFF

George H. Davis has been selected to be the new chairman of the Department of Geosciences at the University of Arizona (Tucson) in July 1982, after having taught 12 years at U of A. Dr. Davis replaces Edgar J. McCullough, Jr., department head for 12 years.

L. Paul Knauth is the new chairman of the Department of Geology at Arizona State University in Tempe (July 1982). Dr. Knauth has been with the university since 1979 and follows David Krinsley, the former department chairman (1976–1982).

Michael Morales has been appointed Curator of Geology at the Museum of Northern Arizona, Flagstaff. Dr. Morales will leave the University of California at Berkeley to join NAU staff in September 1982.

David W. Thayer is the newly appointed Curator of Earth Sciences at the Arizona-Sonora Desert Museum (March 1982). Founder of two of Arizona's three speleological organizations, Thayer has taught geology at Yavapai College in Prescott since 1974.

STATE/REGIONAL EVENTS

Museum of Northern Arizona—35th Annual Geology Symposium, Flagstaff, August 27, 1982.

Denver Region Exploration Geologists Society—Meeting, Genesis of Rocky Mountain ore deposits, Denver, November 4–5, 1982.

ANNOUNCEMENT

The following information may be added to the 'Federal Agencies In Arizona' listing in the March 1982 issue of Fieldnotes.

The U.S. Forest Service employs personnel dealing with earth science-related matters—geology, minerals, and mining—on forest lands. These services are maintained at a zone office in Phoenix at 522 N. Central Ave., Room 202, Phoenix, Arizona 85004 (602/261-4372).

Orbicular Rocks Near Kingman

by Howard L. Stensrud
Professor of Geology, Department of Geology and Physical Science, California State University, Chico, California

A small outcrop of igneous rock displaying orbicular structures has been located near Kingman, Arizona, the second known occurrence in the state. The orbicular rock was discovered during field work related to a NSF-funded regional geologic study of the west-central Hualapai Mountains (see Stensrud and More, 1980). Orbicular rocks contain orbicules which consist of a central core surrounded by one or more concentric shells. They are uncommon, unusual, and petrographically distinctive (see Figure 1). One theory holds that orbicular rocks represent some kind of inclusion in magma, that these igneous rocks formed when reacting with the melt. Orbicular rocks sporadically occur in limited areas throughout the world. A review paper of world-wide occurrences, descriptions, and proposed modes of origin for orbicular structures was published by Leveson (1966). At that time there was one known occurrence of orbicular rocks in Arizona, near Tucson.

The orbicular structures south of Kingman are in a 100-by-200-foot area within altered andesitic dike-rock of uncertain age, located about .1 mile east of the ATSF railroad tracks in the NW¼ sec. 4, T. 20 N., R. 17 W., Kingman, Arizona 7½ minute quadrangle. Hydrothermally altered, coarse-grained granite of Precambrian age crops out nearby.

The orbicules are small (.5 to 1.5 cm across), irregularly spaced, and comprise 5-10 percent of the rock (Figure 1 is volumetrically atypical). Most orbicules contain a single shell of granular texture, 1-2 mm thick, surrounding a core which is texturally and compositionally dissimilar to the matrix. An unusual and possibly unique aspect of the Kingman orbicules is the occurrence of up to 20 percent fluorite within the orbicule shell, and lesser, but recognizable amounts in the cores.

This occurrence should be added to the list of interesting and unusual rocks that occur in Arizona.

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Leveson, David J., 1966, Orbicular rocks: a review: Geological Society of America Bulletin, v. 77, p. 409–426.

Stensrud, Howard L., and More, Syver, 1980, Precambrian geology and massive sulfide environments of the west-central Hualapai Mountains, Mohave County, Arizona—a preliminary report: Arizona Geological Society Digest 12, p. 155–166.

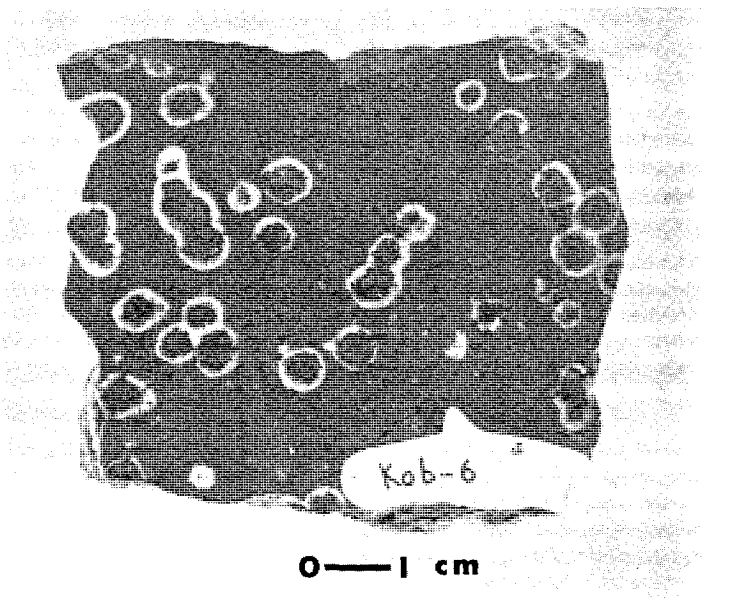

Figure 1. Cut slab of orbicular rock from Kingman area.

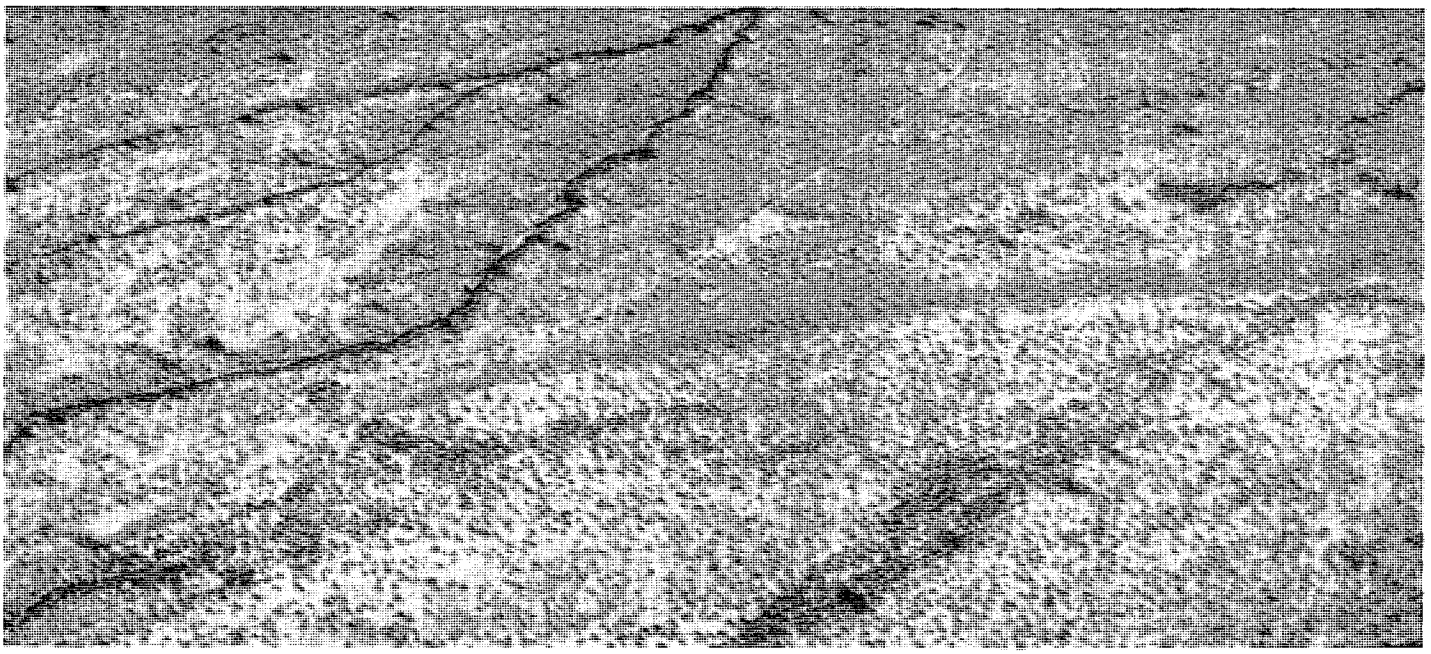

Figure 1. Aerial view of one of the scarp like features in the Hassayampa area (May 25, 1982). Photo: Christopher Menges.

Scarp Features—not young faults

by H. Wesley Peirce

In June 1982, media publicity was given to some geologic features located about 10 miles northeast of the Palo Verde Nuclear Power Plant. These features, called scarps, were encountered by Christopher M. Menges, Research Geologist at the Arizona Bureau of Geology and Mineral Technology, in connection with a statewide study of young faulting in the state. This study, financed by the U.S. Geological Survey, made use of high-altitude U2 aerial photography and subsequent field investigations of possible young fault-related phenomena identified in the photos.

The best evidence for young faulting (within the last 1-2 million years) is to actually see a fault plane cutting young geologic materials. Normally, faults cutting young material cannot be seen directly because of modifications rendered by subsequent erosion and deposition. Consequently, proving the existence of a young fault usually requires trenching to produce a fresh exposure. In the absence of actual observation of a fault, terms such as "possible" and "probable" are used, depending on the evidence associated with a given land form feature.

In the present case, Menges made aerial photographs, visited the site on the ground, and flew over it. From these studies he was not able to convince himself that the scarps were not young fault scarps. As a consequence, he classified them as having been caused by "possible" faults.

The Bureau of Geology and Mineral Technology has been in close contact with the U.S. Nuclear Regulatory Commission (NRC) throughout the site investigation and construction phases of the nuclear plant. After determining his findings, Menges informed the NRC, which, in turn, notified Arizona Public Service (APS), the company responsible for the safety, construction, and operation of the plant. The company's geological consultant, John Scott, was contacted by APS. Scott flew over the scarp site and then visited it on the ground with Menges. Their opinions differed and both recognized that the only way to solve the question of scarp origin was to dig trenches across the most suspicious looking features. Before the trenching was done, APS issued a press release summarizing the situation. Shortly thereafter, two trenches were dug by APS. These trenches demonstrated, unequivocally, that the scarp features were not caused by faulting. Rather, they were caused by a complex combination of erosional and depositional processes.

Figure 2. Trench excavated across a scarp, which demonstrated a non-fault origin (June 13, 1982). Photo: Christopher Menges.

RECENT PAPERS ON ARIZONA GEOLOGY

The Geological Society of America Cordilleran Section held its 78th annual meeting April 19-21, 1982 in Anaheim, Calif. Listed below are the authors and titles of some of the presentations on Arizona geology.

Anderson, R. Ernest: Miocene structural history south of Lake Mead, Nevada-Arizona.

Anderson, R. Ernest, Fleck, Robert J., and Bohannon, Robert G.: The Las Vegas valley shear zone, Lake Mead fault system, and extensional tectonics; Lake Mead-Las Vegas valley region, southern Nevada, northwestern Arizona, and southwestern Utah.

Bilodeau, William L.: Basin configuration as a control on the geometry of Laramide deformation in SE Arizona, SW New Mexico, and NE Mexico.

Blakey, Ronald C., and Gubitosa, Richard: Controls of sandbody geometry in the Chinle Formation (Upper Triassic) Colorado Plateau.

Conway, Clay M., Wrucke, Chester T., Ludwig, Kenneth W., and Silver, Leon T.: Structures of the Proterozoic Mazatzal orogeny, Arizona.

Crespi, Jean M., Currier, Debra A., Ditullio, Lee D., Kauffman, Ann Bykerk and Krantz, Robert W.: Superposed faulting in the Huachuca Mountains, southeastern Arizona.

DeWitt, Ed: The geochemistry of Precambrian crust and its effect on younger metallogenesis, Yavapai County, Arizona.

Dickinson, William R.: Space-time evolution of Cretaceous-Tertiary tectonomagmatic provinces in the southwestern United States.

Farmer, G. Lang, and DePaolo, D. J.: A Nd and Sr isotopic study of the hydrothermally altered Laramide porphyry at San Manuel, Arizona.

Frost, Eric G., Martin, Donna L., and Krummenacher, Daniel: Mid-Tertiary detachment faulting in southwestern Arizona and southeastern California and its overprint on the Vincent thrust system.

Grover, Jeffrey A.: Depositional environment and structural relations of the Mineta Formation, Teran basin, Cochise County, Arizona.

Guilbert, John M.: Metallogenic aspects of porphyry copper-molybdenum deposits of Cordilleran North America.

Harding, L. E., Coney, P. J., and Butler, R. F.: Stratigraphy, sedimentary petrology, structure and paleomagnetism of the McCoy Mtns.-Livingston Hills Fm., SE California and SW Arizona.

Haxel, Gordon, Mueller, Karl, Frost, Eric, and Silver, Leon T.: Mid-Tertiary detachment faulting in the northernmost Mohawk Mountains, southwestern Arizona.

Hereford, Richard: Alluvial stratigraphy and discharge of the Little Colorado River, Arizona since 1927.

Huyck, Holly L.: Mineralization of the Lakeshore porphyry copper deposit, Pinal County, Arizona.

John, Barbara E., and Howard, Keith A.: Multiple low-angle Tertiary faults in the Chemehuevi and Mohave Mountains, California and Arizona.

Karlstrom, Thor N. V.: Dating of the type Tsegi and Naha deposits of Holocene age in the American Southwest.

Keith, Stanley B.: Evidence for late Laramide southwest vergent underthrusting in southeast California, southern Arizona, and northeast Sonora.

Keith, Stanley, B.: Laramide structural, magmatic, and metallogenic evolution of southeast California, southern Arizona, and southwest New Mexico.

Larson, Michael K., and Péwé, Troy L.: Investigation and prediction of earth fissures related to ground-water withdrawal, Phoenix, Arizona.

Light, Thomas D., Marsh, Sherman P., and Raines, Gary L.: Mineralization in the Crossman Peak area, Mohave Mountains, Arizona.

Lingrey, S. H., and Davis, G. H.: Kinematic/geometric evolution of the Rincon Mountains metamorphic core complex, southern Arizona.

Lucchitta, Ivo, and Suneson, Neil: Relationship of core complexes, Cenozoic extensional tectonism, and the stable craton near the Colorado Plateau margin in western Arizona.

Mayer, Larry: Constraints on morphologic-age estimation of Quaternary fault scarps based on statistical analyses of scarps in the Basin and Range province, Arizona, and northeastern Sonora, Mexico.

Menges, Christopher M., Pearthree, Philip A., and Calvo, Susanna: Quaternary faulting in southeast Arizona and adjacent Sonora, Mexico.

Morrison, Roger B., and Menges, Christopher M.: Late Pliocene and Quaternary Geology of Arizona.

Moyer, Thomas C., and Sheridan, Michael F.: Bimodal volcanism in the Kaiser Spring area, SE Mohave County, Arizona.

Newell, Roger A.: Geologic setting and geology of lead-zinc-silver deposits of the Tombstone district, Cochise County, Arizona.

Nutt, Constance J.: A model of uranium mineralization in the Dripping Spring Quartzite, Gila County, Arizona.

Otton, J. K.: Involvement of a Mesozoic to early Tertiary thrust terrane in mid-Tertiary crustal extension, west-central Arizona.

Otton, J. K.: Petrogenetic evolution of mid-to late-Tertiary magmatism and associated metal deposits in west-central Arizona.

Ratte, James C., Marvin, Richard F., and Naeser, Charles W.: Tectonic setting and geology of base and precious metal deposits, southwestern Mogollon-Datil volcanic field, New Mexico and Arizona.

Reynolds, Stephen J.: Superimposed Mesozoic and Cenozoic tectonics, west-central Arizona.

Reynolds, Stephen J., Keith, Stanley B., and DeWitt, Ed: Late Cretaceous-early Tertiary peraluminous granitoids of Arizona—California and their related mineral deposits.

Richard, Stephen M.: Structure and stratigraphy of the Little Harquahala Mountains, Yuma County, Arizona.

Shakel, D. W.: Yet another model for metallogenesis of Arizona copper: exclusively Precambrian primary crustal emplacement, storage in selected sedimentary sequences, and concentration by fortuitous Phanerozoic magmatism of various ages and origins.

Strand, Carl L., and Scacifero, Anthony J.: Quaternary fault studies in the Arizona mountain neotectonic province.

Swan, Monte M.: Influence of pre-Cretaceous structure upon Late Cretaceous-Tertiary magmatism in southern Arizona and New Mexico.

Theodore, Ted G., McKee, E. H., Nash, J. Thomas, and Antweiler, John C.: Genesis of Late Cretaceous gold mineralization in the Gold Basin-Lost Basin mining districts, Mohave County, Arizona.

Tosdal, R. M., and Haxel, Gordon: Two belts of Late Cretaceous to early Tertiary crystalline thrust faults in southwest Arizona and southeastern California.

Wilkins, Joe, Jr., and Heidrick, Tom L.: Base and precious metal mineralization related to low-angle tectonic features in the Whipple Mountains, California and Buckskin Mountains, Arizona.

EARTH SCIENCE CENTER II: Gateway to the Past

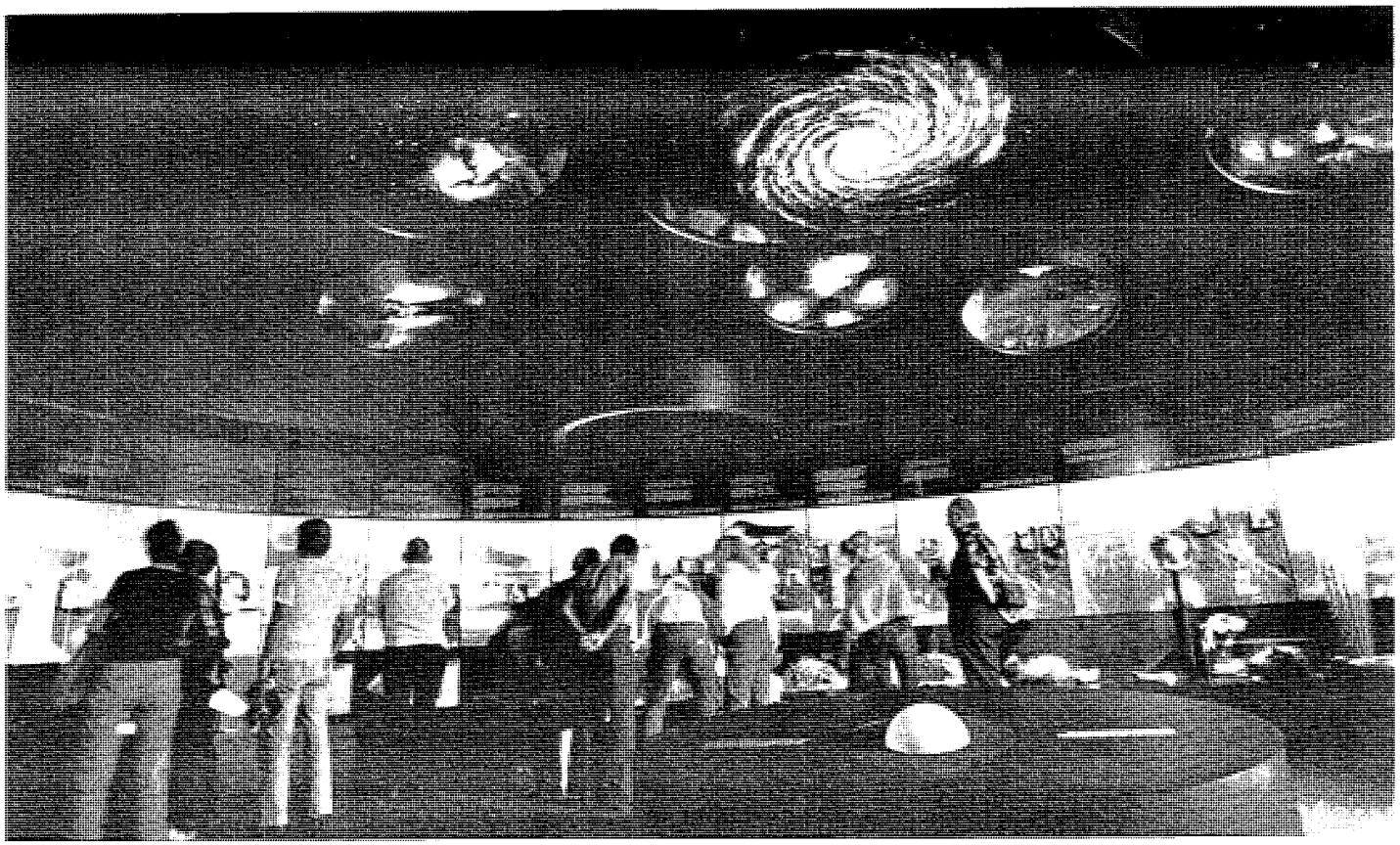

Figure 1. Beneath a transparency of a painting of the Milky Way and photographs of various nebulae in our galaxy, visitors to the final phase of the Stephen H. Congdon Earth Sciences Center at the Arizona-Sonora Desert Museum trace the 5-billion-year history of the Sonoran Desert. Photo: Arizona-Sonora Desert Museum.

"Over three billion years ago, the earth was in nearly total darkness." So begins the story of this planet's geologic history, in the recently completed gallery at the Arizona-Sonora Desert Museum's Earth Science Center. Scores of exhibits composed of living plants, fossils, photographs, models and artists' works line the walls and ceiling of the elliptical gallery, leading the visitor through geologic time and environmental change.

One can move through the past at an incredible pace in the gallery, viewing occurrences in the earth's development, under a canopy of stars and nebulae. The displays depict the emergence of life through the development of photosynthesis and the formation of an oxygen atmosphere three billion years (b.y.) ago. A sample of the oldest known rock (3 b.y. old metaquartzite from Greenland) is displayed, followed by the earliest known single-cell fossil (1.3 b.y. old) and a single-cell algae fossil from the Grand Canyon, dating 800 million years (m.y.) ago.

Arizona's evolution is outlined: 800–250 m.y. ago, shallow seas covered parts of the state; a coastal plain emerged, with present-day Tucson on the shoreline of an ancient sea, about 250 m.y. ago. Geologic upheavals occurred: Intense volcanic activity formed Arizona's copper deposits 180 m.y. ago at Bisbee; 70–60 m.y. ago the crust was buckled and deformed. One m.y. ago glaciers covered the state's highest peaks and valleys, and the land was surrounded by lush vegetation and water. Twelve thousand years ago, man roamed the area, along with large mammals (horses, bison, ground sloths, camels, mammoths, and sabre tooth cats, extinct by 8,000 B.C.).

A glimpse of the future is provided in an exhibit that wraps up this geologic tour through time. It is projected that climatic changes will occur as the Baja Peninsula breaks away from the continent and moves northward, merging the Gulf of California with the Pacific Ocean.

A unique, circular screen, 15 inches in diameter, occupies the center of the gallery (see Figure 1). This three-dimensional 'orb' depicts 'continental drift' through plate tectonics, as land masses appear to combine, separate, and recombine (e.g., 300 m.y. ago, Arizona was located near present-day Brazil).

The gallery exhibit blends into a hall of minerals and crystals native to Arizona. Precious and semi-precious stones, faceted gems, and micro-minerals sparkle in the dimly lit room. Displays emphasize the importance of copper in the state and nation. For instance, about 150,000 tons of the earth's crust yield enough copper to make a penny; and a person uses 1,750 pounds of copper in a lifetime (represented by a copper cube 17½ inches per side).

The mineral hall leads the visitor through a reconstructed mine tunnel containing four vugs (pockets) of crystals (selenite, wulfenite and mimetite, vanadinite, and malachite) as they actually appear underground. The exhibit ends with a simulated mine dump.

The Earth Science Center II was completed and dedicated in the fall of 1981, following the considerable success of phase I (reconstructed wet and dry caves), finished in 1977. The Potomac Group (Washington, D.C.) designed phase II and General Exhibits (Chicago) created most of the displays, in conjunction with museum staff. Construction and assembly of phase II was performed by museum staff. Implementation of the entire Stephen H. Congdon earth science complex was made possible through bequests and donations from private individuals and industries in Arizona. The total cost was $1.5 million, $700,000 of which went to phase II (see Fieldnotes, v. 10, no. 4, p. 9).

BUREAU PUBLICATIONS

Circular 23, **Geothermal Resources in Arizona: A Bibliography,** by Susanna Calvo; 23 pages; $3.00. Reference reports and maps generated by the Arizona Bureau of Geology and Mineral Technology Geothermal Project and by the Arizona Geothermal Commercialization Team of the Department of Chemical Engineering, University of Arizona, Tucson. Other references include other fields closely related to geothermal (geology, hydrology, geophysics and geochemistry); funding from the U.S. Department of Energy, the U.S. Bureau of Reclamation, and the Arizona Solar Energy Commission.

Geothermal Resources of Arizona, a 1:500,000-scale map, is now available from the Arizona Bureau of Geology and Mineral Technology for $1.00, which includes postage and handling. The study was funded by the Department of Energy; the map was prepared for and printed by the National Oceanic and Atmospheric Administration, and compiled and interpreted by James C. Witcher, Claudia Stone, and W. Richard Hahman, Sr.

Historical Seismicity in Arizona: Final Report, Open-File Report 82-2, by Susan M. DuBois, Marc L. Sbar, and Thaddeus A. Nowak, Jr.; 199 pages with maps; $20.00. Contains epicenter maps (by intensity/magnitude category or by time period), earthquake reports (epicenter, intensity, and date), discussion of tectonic setting of Arizona, seismograph data, and summary of 1887 earthquake (includes attenuation data); funding by Arizona Bureau of Geology and Mineral Technology, U.S. Geological Survey, and U.S. Nuclear Regulatory Commission.

These publications may be obtained from the Arizona Bureau of Geology and Mineral Technology Publications Desk or by mail (with 20% handling charge).

NEW PUBLICATION

Anderson-Hamilton Volume: **Mesozoic-Cenozoic Tectonic Evolution of the Colorado River Region, California, Arizona, and Nevada,** edited by Eric Frost and Donna Martin; 616 pages with nearly 200 photos. Compilation of 77 authors' studies, from the U.S. Geological Survey, the U.S. Bureau of Mines, and many universities and industry; obtained from Cordilleran Publishers, 6203 Lake Alturas Ave., San Diego, California, 92119, for $25.00 plus $2.50 postage and handling.

REQUEST FOR GEOLOGIC DATA

The Arizona Bureau of Geology and Mineral Technology is presently compiling geologic mapping and radiometric ages for the areas covered by the Tucson, Phoenix, and Nogales 1 x 2° Quadrangles (scale 1:250,000). Anyone possessing unpublished geologic mapping or radiometric ages in these areas is asked to contact Stephen Reynolds, Arizona Bureau of Geology and Mineral Technology at 845 N. Park Ave., Tucson, Arizona 85719 (602/626-2733).

Fieldnotes is a 12-page newsletter published quarterly by the Arizona Bureau of Geology and Mineral Technology. A subscription is free of charge and may be obtained by contacting the Arizona Bureau at 845 N. Park Ave., Tucson, Arizona 85719 (602/626-2733). Address changes should accompany the previous address label, if possible.

ARIZONA GEOLOGICAL SOCIETY FIELD TRIP

The Arizona Geological Society Spring Field Trip, led by Dr. Larry K. Lepley, was held May 1, 1982 in Safford, Arizona. The purpose of the trip was to compare images derived from an aerial multispectral scanner designed to simulate the Thematic Mapper to be included on the future Landsat D satellite.

The area examined on this field trip is one of three porphyry copper deposits evaluated, under contract with the National Aeronautics and Space Administration (NASA), as part of a joint NASA-Geosat test case study by the Jet Propulsion Laboratory (JPL), California Institute of Technology, and geologists from U.S. mineral and petroleum exploration companies, under the auspices of the Geosat Committee, Inc. Project goals were: 1) to evaluate remote sensing techniques for detection of alteration, structures, and stratigraphy associated with porphyry copper deposits, and 2) to make recommendations for future sensor systems more applicable to exploration problems.

Three areas in Arizona—Safford, Helvetia, and Silver Bell—were selected for evaluation because they include a variety of copper occurrences in a semi-arid climate with different host rocks, levels of erosion, and stages of development. Research on the project was done by Michael Abrams, JPL, California Institute of Technology, Pasadena; David Brown, Texasgulf, Tucson; L. K. Lepley, Consultant, Tucson; and Ray Sadowski, AMAX, Tucson.

A limited number of the field trip guidebook, "Comparison of NASA Thematic Mapper Images of the Safford District with exposed alteration haloes at the Phelps Dodge Dos Pobres and Kennecott Lone Star deposits" are available for purchase from the Arizona Geological Society, P.O. Box 40952, Tucson, Arizona 85717 ($35.00); the guidebook may also be reviewed at the Arizona Bureau of Geology and Mineral Technology Library.

BUREAU OUTREACH

In February 1982 Dr. H. Wesley Peirce talked to students, faculty, and guests of the Northern Arizona University Geology Department. He discussed the history and origin of Oak Creek Canyon, an outgrowth of his work along the Mogollon Rim, noting that the geologic history was considerably more complex than previously thought. In particular, he pointed out the necessity of understanding the geologic history of the Oak Creek fault zone, if canyon genesis is to be properly comprehended.

In April, Dr. Peirce attended the 18th Forum on Geology of Industrial Minerals, held on the campus of Indiana University at Bloomington. The meeting was sponsored by the Indiana Geological Survey and the Department of Geology. Field trips included visits to: 1) one of the nation's largest gypsum mining (underground) and product processing facilities; 2) the center of Indiana's famous dimension-limestone quarrying and milling industry; and 3) both surface and underground mining operations that produce vital aggregate for the Indianapolis region. Such meetings are of interest to the Bureau because of its continuing efforts to remain informed about how rocks and minerals of all kinds are exploited, processed, and utilized. As the population of the Southwest continues to grow, and technology evolves, demands for an ever enlarging array of rock-based natural resources are increasing. The Arizona Bureau of Geology and Mineral Technology will host the 21st Forum in 1985.

In May, Peirce was one of three scientists taking part in a program arranged for an American College of Physician's Arizona Section Meeting at Sedona. Using slides, he illustrated what Arizona is, geologically, and how its inherited geologic characteristics control where we live and what we do [no rocks—no doctors!].

In June 1982 Dr. Peirce was a participant in a Natural Resources Workshop for Arizona Youth, sponsored by the Society for Range Management. Forty-five young men and women gathered at a camp facility in the Prescott National Forest for a week of natural resources-related instruction and field activity. Peirce emphasized the fundamental ecological role of rocks, minerals, and soils.

Dr. Larry Fellows attended the 74th Annual Meeting of the Association of American State Geologists in Hershey, Pennsylvania, in early June 1982. The meeting was hosted by the Pennsylvania Bureau of Topographic and Geologic Survey. Each year state geologists, selected state geological survey staff, and invited guests (including federal agency directors and staff) meet to inform each other about current or projected activities, to discuss problems and projects of mutual interest, and to identify ways of cooperating. Forty states were represented.

This year attention was focused on the effects of state and federal budget reductions on providing geologic data and service pertaining to the management of land, mineral, water, and energy resources. Another topic of considerable interest was the establishment by Secretary of Interior James Watt, of the Minerals Management Service, which is comprised primarily of what formerly was the Conservation Division of the U.S. Geological Survey. Representatives of western states were particularly interested in learning about the Geology, Energy, and Minerals (GEM) assessment program, recently initiated by the U.S. Bureau of Land Management.

Dr. Stephen J. Reynolds, geologist with the Arizona Bureau of Geology and Mineral Technology, has lectured at various universities, state agencies, and professional conferences. Early in the year, he delivered formal presentations at the University of Arizona and Northern Arizona University. In both cases, he discussed the major thrust faults that he and other workers have recently mapped in western Arizona.

Dr. Reynolds was also invited to present talks to other universities in the western United States. For these occasions, Steve's travel expenses were paid by out-of-state universities. At San Diego State Univ. last March, Reynolds presented the results of his geologic research in west-central Arizona, an area of complicated faulting and folding. He also spent much time in the classroom with professor Eric Frost and his students, discussing their geologic studies along the lower Colorado River. Reynolds later traveled to the University of Texas at El Paso to talk about whether the overthrust belt, an area favorable for petroleum (see page 5), actually extends through southern Arizona, as some geologists have proposed. Reynolds concluded that an overthrust belt, like that known in Utah and Nevada, does not cross southern Arizona. He discussed these conclusions with UTEP professors who have geophysical and stratigraphic data that bear on the issue. In May, Reynolds presented a talk to the University of California at Davis on his research in Phoenix South Mountain Park, and conferred with professors and students at Davis about their planned microsopic studies of selected rocks from the South Mountains.

Dr. Reynolds also delivered two scientific talks at the annual meeting of the Geological Society of America Cordilleran Section, in Anaheim, California (see page 9). One talk concerned a certain type of granite in Arizona and its potential for mineral deposits. At the other session, Reynolds described the age of faulting and mountain building in west-central Arizona. He also participated in pre-and post-meeting field trips in western Arizona and adjacent southeastern California. These field trips were well attended by geologists from various companies, universities, and federal agencies.

Reynolds has also given nontechnical talks on the geology of Arizona to various state agencies of Arizona (Departments of Water Resources, Transportation, Land, Mineral Resources, and Health Services; State Library, and Office of Economic Planning and Development). At these talks, Dr. Reynolds utilized color slides and maps to illustrate how the major geologic features of Arizona influence our daily lives.

Fieldnotes

Volume 12 No. 2 June 1982

State of Arizona ..... Governor Bruce Babbitt
University of Arizona ..... President Henry Koffler
Bureau of Geology & Mineral Technology
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Southwestern Exploration Division

September 23, 1977

TO: J. D. Sell
G. W. Pickard
G. J. Stathis
H. G. Kreis
S. R. Davis
B. J. Devere
P. G. Vikre
D. M. Smith
W. L. Kurtz
J. H. Courtright

FROM: F. T. Graybeal

Silver City, New Mexico
Field Trip
Oct. 3-6, 1977

The itinerary now looks as follows:

Monday	Oct. 3 AM	- drive to Tyrone
	Oct. 3 PM	- Tyrone Mine with Joe Kolessar
Tuesday	Oct. 4 AM	- Santa Rita Mine with Bill Baltosser or Paul Novotny
	Oct. 4 PM	- Continental Mine with Ernie Ahrens
Wednesday	Oct. 5 AM	- Ground Hog Mine with Tony Dalla Vista, Robin Hickson, Sal Anzalone
	Oct. 5 PM	- possibly more Ground Hog or other geologic features in the Silver City area; drive to Clifton, Arizona
Thursday	Oct. 6 AM	- Morenci Mine with Ken Bennett
	Oct. 6 PM	- Cyprus Johnson Mine with Bob Clayton or mine staff; return to Tucson

Monday and Tuesday nights we will be at the Holiday Motel in Silver City (505-538-3711) and Wednesday night at the Coronado Lodge in Clifton (865-2132). The evening session(s) will be at the Holiday Motel as mentioned in my earlier note.

Aside from the formal tours there are several additional features of interest in the Silver City area which we will probably have time to see. Hernon and Jones give a good summary of ore deposits in the Central Mining District in the Graton-Sales Volume which you all should read. There is, in addition, a voluminous amount of literature on this area in our library.

Our departure will be Monday, Oct. 3, 1977, at 8:00 AM from the Tucson Office. S. R. Davis, H. G. Kreis, and G. W. Pickard have kindly been volunteered to drive.

F. T. Graybeal

F. T. Graybeal

FTG:lb

Field Notes

Johnson Camp
Cyprus
10-6-77

Joe — Supt.
Prod.: 4000 tpd - (w/o 1.5%) oxide ore (mainly chrys.) to leach dump — 20' increments.

Mine ± 200' thickness thin bedded Abrigo — dipping 30-40° easterly. 7 year life — ± .8% Cu

Pregnant solution to LIX plant produces 99.5(?)% copper —

In pit ore is blocky, brittle — breaks down thru handling — to ± 80% minus 2" on leach dump.

Skarn ore — diopside-garnet purportedly related to Texas Canyon biotite qtz monz (53 my) stock, but more likely associated with separate intrusive to east, under cover. Numerous qtz veins in ore.

JHC

Field Notes — Ground Hog

(Supt: Robin T. Hickson) — 10-5-77

Tony Dallavista —

Went down Star shaft to 1600 level — proceeded NE to several stopes —

Typical ore body ≠ 20' x 30' x 60' localized along dikes ~~at~~ or pre min fault — massive sphalerite — minor galena, cpy — strong hedenbergite on ls. (Hanover) contact. occasionally mining min extends out into ls bedding

400 tpd — 6 days week

Grade: 11.0 Zn, 2 Pb, .8 Cu, 1.0 oz Ag

5 yr reserve — 550,000 tons

2200 (deepest level) under water

pump 400 gpm

Down to 1950 level — Then back to collar

Need full time geologist —

plus a new drill — have one good one and one antique —

Pay Kenn (on Ivanhoe — ~~2~~ 8% roy.

— little better than a breakeven at present

Open stope mining on NE, sand fill on southW — in some stopes

Field Notes

Pinos Altos N.M.
Exxon

Drilling around periphery of stock passed thru post mineral volcanics, pre mineral Silver Bell andesite — upper Cret Col. shale Beartooth qtzite — into paleozoic limestone containing skarn beds — mineralized — Syrena, Oswaldo and Lake Valley fms. — a few holes penetrated Percha shale.

Stock (70 M.y.) contains gold-qtz minor Zn-pb veins — worked in early days — a few patches wkly alt-min stkwks, but in general stock appears hungry — unaltered barren

Rumored: 30 million tons 2.0% Cu, 4% Zn. 2 or three drill rigs still going — depth of "ore": 400' to 1500'.

RTR

Denver - 6-8-76

Huckley Dome

Warren Ranch

no 2 hole 305' casing — then 100' cement. — py
2nd plug (200') at 800' — TD 1406 stopped in anhydrite
~~Deering - 4C4~~ 1378 — 1379 - 8% rec Ls .19 pb in ls
1379 - 1400 99% " sh + anigh - py & pb
pb in FeS

Wood Derrick — (~~Deering no 5~~) 54' 20% pb — 1448 - 1454

log from Houston Pub Lib | Deering No 4 — 950' 5ks of Wood Derrick 1448 - 1454 —
pb in FeS below sandy shale — no ls logged
≈700 — Ls bx - vuggy — py — oil —
NoH-3 — 940 ≈ 1054 — Zn in anhydrite
30' 3.59 comb (Zn 1.5) sph colorless not identifiable in core.
sh shale
960 broken gray ls
drilled in 1940's FS 4 ls ≈ 980 - 990 30% rec. gray calcite ls with galena
990' - 1000 20% rec. gal and other sulphides
1000 1010 - 10% - "
1020 - 20% " + ls
9" core 1030 25% "
39 10% "
48 country
1052 Anhydrite

July 11, 1976 prop — 5000 in taxes
~~taxes~~ plus 22,000 premium on drilling —

Take it to Free point — They know about info in drilling salt domes — offer joint V — ~~on~~ on materials, expend — or start from scratch
include other domes?

or — spend to equal prop purchase 25,000 —

5-11-76
Springbok

With Tim Mueller, Doc & 35 miles SW by road to Kraalfontein prospect — narrow ± 6" discontinuous gossan in gneissoid granite — area ± 100 m dia — prospect shaft 30 m deep — minor grains and masses cpy on dump — PD drilled to down hole hammer holes — dropped.

Two ~~diff~~ separate gos samples run ± .5 pb- and Zn — no Cu. Gossan shows mainly cpy bxwk — hematite — son poss sph bxwk entire toss. limited in extent — Doc took sample to chk Cu and Ag. Possibly son diss min — but minor extent —

PM to Hester Maria 10 Km NNE Springbok O Kirp Min district — took picture of Simon VanderStel — oldest min in SA ± 1680 now National park — cpy in Noritoid — visible as ~~dak~~ darker color (lensoid) in gneisses — intrusive into flat structure — foliation — warped up to vert along walls of noritoid — ± 3 m wide at Hester — discontinuous intrusion along ± 200 m str length — cpy bxwk in gossan — a few grains cpy-bn on dumps — gneissoid belt Min age 11 hundred m yrs —

To Tims office — specimens of Gansberg incline — py-po — sph as grains and masses (one spec. strong galena) ± 1" dia in magnetite qzite (dark to blk) — Mag in outcrop (atypical) spec.

One piece of float found on Hermitage Holt Mag qzite — tiny flakes yellow brn — may be alter sph — over

Arries — 120 km to N West Springbok
float in soil and caliche — transported cover
in part — no outcrops found in shallow
trenches — room for substantial sized
min zone between barren outcrops —
gossan float: dark brownish —
dense siliceous ferruginous — a few
cavities with thin wall bxwk — could be
siliceous supergene cap — pitting planned
Okiep Copper — data on new
development? — Doc has in office
from field trip — ± 20 mil tons —

chk

Cost R 11-12 per ton min milling - total
including interest payments
~~pay~~ Probably sizeable

5-13-76
Prieska -

By charter plane with Hein + Tim from Upington to Copperton - R. Green acting Gen Mgr., Tom Espach asst mine mgr - Johan Giezing, chgeol; Hannes Wagener asst chgeol -

Down jeep incline (6 to 1) - to 130 M level - saw amphibolite gneiss footwall - original dacite -? - then 12" banded (bedding?) dolomite with massive sulf on either side - Then x cut into h.w. - amphib schist - Then massive to 50% Sulf - x section show ± 50 M dolomite over ore dip 50° NE - One zone up to 30 M wide av - 10 M - pinches to sub marg. thickness in large areas. Minor barite and MoS_2 - One Av ± 40% Sulf varies from massive to somewhat dis - stringers blebs - Ca Mg Car gangue - some gneiss - Sad series quartzoid qtzite etc on hanging - Post min intrusive amphibolite.

Mine 8-10 Thousand Tons day 6 days wk - Developed to 420 - main mine level 320 M 8 yd scooptram - ring drilling (25 m max hole) sublevel open stoping - weak shear zone in ft wl - dilution 10-20% - will try hang wall approach - 800 M max depth exp! still going -

drilled 5 airborne EM - one smaller lower gr body 5 Km So.

Leached ± 100 m - one small outcrop area - ± 50 mts long - dense jasperoid or chalcedonic cap - ± 2 m deep - shows some bxwk remnants - ~~pit shows~~ old dump by shaft - contain soft gossan frame - bxwk + lim after cpy - py minor amts flakes bx after ~~mag~~ Fe 5? - Over

Lunch and mgr mess. — formal attire —
after chat outcrop — looked over core —
then by charter to Kimberly — took
shots of "dig hole" started in 1886
5 or 6 others — ~~#~~ some now operating
50,000 tpd total —
on commercial fl to Jo'burg
Pretoria — on extension flat plain
shallow cover — lineam n to Greachop
low gr (.5 cm 2.0 cm) — so E under
Karoo

Elev – ± 5000'

5-7-76

Visit to Oamites – ~~50~~ 45 km so of Windhoek –
Arnold Kleyenstuber, mine geologist – Gervais acting mgr
Stratiform Cu-Ag deposit in late Proto qtzite and schists
congl. ~~Str E-W~~ ENE, dip near vert. Ore body (av. 1.3 Cu .33 Ag)
up to 30 m wide (av. 16 m) is 600 m long – 400 M depth
Expl drilling to 600 M depth – narrow lo gr –
best grade: finely disem bn-cc in qtzite with tr to 1% cpy
Outcrop form prominent ridge – brownish stain – chrys
in grains replacing bn, cc, cpy – minor lim after py – very
little lim (dark red) after cc or cpy. channel samples ~~at~~ 40 M
in ends average 1.01% Cu – Ag not assayed – Ave depth
oxid (essentially in place) 40 M – (200-300 M
on shear x cutting ore beds) – ~~one~~ favorable
horizon traced over ~~6~~ 1.5 km total length – appears to pinch out.
Mine at 2000 tpd 6 days week – 14° declines – for access – ~~5~~ 5 yd scoop trams and ~~pa~~ landrovers – 3 x 5 meter passageways – sublevel stoping – ring drilling – 25% left as pillars eventually be recov. ground stands perfectly, except on shear where cave to surface recently took place – ~~ore~~ ore crushed underground to ~~mill~~ on surface by conveyor belt. Recov 94% Cu-Ag – conc 42% Cu – grind 50% minus 120 mesh – have mined 2 mill – 6 m reserves. Operating cost R 5.5 total to railroad (To Tsumeb smelter) R 7.5 current grade 1.3 Cu 1.5 Ag – cut off .7 Cu according to Lee and Glennie (Econ geol, Vol 71, 1976) –
DD AX – standard – no recov problem – ~~questionable~~ profit

Currently collaring expl DD holes at 80° → 50° → 200 m → 50 M apart
15 M pillars

Will take chips for Cu + Ag no Ag Assays 5-9-76

To Rooibokop — C Lombard — camp on River non magnetic
to shaft dump — Remnants cpy (and bn?) + po —
adit — ± 13 M — ± 10 M min zone dip
NE 65° — Cu Sulphate coating — patchy —
indicate poss average .5 to 1% Cu —
much speculate and lim after spec
Very prom outcrop — very cre qz on both
sides — crumbly — low relief —

Outcrop varies from dense massive silica iron oxide to strongly brecciated, occ. to very sparse cpy bx work — some fine cellular after po or py — but mostly after spec — much massive quartz — 25 to 50% — bx zones appear better mineralized — cause of mag anom uncertain — total bx wk after sulphides 3-5% — est grade of primary less than 1% Cu — probably derived from minor cc —

Sulphide in pits in dump and at adit & some bx after spec

Moranda did some work 34 yr ago — thrown off 64 surface "Rooiberg Corner" R600

3 holes 450 M — at R30 = 135 × 0 T1000 mob. — 600 assaying
" " Gar 20,000 —

"Zn" gossan on SE similar but less silica as massive quartz — less prominent ridge — some bx wk possibly after sphalerite — no cpy bx wk, but otherwise similar to Cu bearing gossan — no Cu in chip samples — mag anomaly may be also after po as some possible po bx wk
Total sulps also low max 5% —
Concl — neither has any chance of ore grade —

Together deal on Boshtiaef

Offer for 2nd 15 yr — R500
Cim 44 44 purchase R250,000
R10,000 deposit to go between

3 yrs left on option R200 month
R 400,000 purchase price.

Windhoek — 5-4-76

Pm Drove to Esselmanhar 130 km — 100 km SE

along road so of Windhoek Komas schist gentle dips — qtzites etc — Then granite then Hakos schist 1s quarry

Esselmanhar — trenched by Newmont 8 yrs ago

(Schistos seds dip ~~SE~~ N ± 45°)

(saw group of springboks — gazelles)

Broad flat areas with occ ridge or hill rising up 400-500' — areas in between wind sand and calishe covered — 20-30% out crop overall —

malachite stain ubiquitous — mainly on clear cleavage planes — rare vugs —

with to clear qtz masses and veins parallel to schistos — very minor grains and seams cu pitch — some dark red limonite poss after cpy — some lt brown after iron sulfide — some black coating MnO? — trenches ± 4' deep now sloughed in — out crops generally sparse but if all ~~pit ex~~ cavities representing sulfs were cpy — average of sulfs over 200' ± .5 Cu at best — probably some malachite enrichment? — Cu seems associated with qtz — much of some schist barren of sul cavities — estimate .3 to .5 Cu over 100-200' (±50 M) — if I 10 chip samples of out crops dont run approx aq — drop prospect — out crop % not more than 20% schist sticks up as narrow ribs — recon prospecting to E I 6 miles (Hein) —

250 Km NNW of Windhoek 5-6-76

To Hagen hof gossan — outcrops bold — highly resistant supergene silica iron ox — some Cu stains (mal) much white qtz — vein ± 15 mt (gossan) width — ± 100 long? Vein str ENE ? PD holes

2 Texas gulf — st NE — E m anom on SW — TGS holes —

See note book on drilling results — ~~st~~ sulphide shoot rakes or plunges low angle to SW — massive + diss sulls — po, py, ~~cp~~ cpy —

deposit not completely tested but enough — — not worth of further work

Thurs mor — examined core from Folle massive po — some py, minor cpy —

No 6

PD holes 6 + 7 (last) ∧ 6-8 M .52 Cu ~~at~~ 74 M depth

No 7 — 18 M .91 at 93 M — po, py, cpy, qtz calcite in qtz bin schist — some mbl —

only 3 holes under gossan —

Old shaft at edge of gossan ± 20 M deep — no sulls ~~on~~ dump — oxid ± 30-50 M deep

Camel Thorn — large seed pods

5-12-76

With Tim Mueller and Hein by car from Windhoek — NE to Hunites-Holte — camp in SW cor. Holte farm — both farms about 20 x 8 Km — EW along Caravan type camp — 2 white goat plus black helper — option entirely covered — generally shallow ± 3 mts — 2 exposure (gneiss) in borrow pits along rd. — mag traverse 400 mts apart on Holte farm — Shows EW trend anom plus 500 gammas + 4 Km long — on Holte farm crosses main rd at ± 15° — picked up one piece of mag qzite float — started ground EM? — plan to detail mag anom — Then sink pits to bedrock — center this area about 20 Km SW Aggeneys Option ? price —

On to Gamsberg — drove up to gossan North dipping ± 20° — base pink gneiss (weathers brown) then schist — Then qtzite then gos overlain by mag qtzite — Then schist — goss in part qzitic — much dense siliceous ferruginous (supergene) — some martite — yellow br flaky — after sph ? — some cavernous — some bx wk after Py-Po —? — yellow brown scratch general area ± 20 % outcrop as prominent hill ± 200 m high — poss 300 m max highly folded —

Cont on to Kakamas — Then move out crop — Cross Orange River — then to Upington area crop — NNW of Upg. 10 Km 8 miles to S Cu 2.2 %

Soil geochem grid 300 x 360 mts 5-6-76

60 km NW of Otjiwarongo 280 NNW Windhoek

To Straussenheim — water well ± 15 m

cut malachite — and gossan — Damara seeds

"gritty" calcareous? qtzite — some pebbly arkosic ± ~~100~~ 60 m wnt tip between

limestone strike E-W — flat terrain —

geochem anom 70 ppm 200 EW ~~100~~ 70 MN S — 130 ppm Cu max

open on west — closed on east 64 from ridge

800 M E — outcrop — two trenches ± 2 m deep

near shaft or well — one 35 m — 7 or 8 m bedrock

qtzite with Cu stain — some limonite cov — some

gossan float — some calich — one 25 m

trench (both N-S) ± 5 m bedrock —

qtzite — ~~some~~ minor min — reported

possible ~~50 to 60~~ wnt thick min

horizon — ~~cutt~~ definitely not close off. — all cover

west pass 800 wnt — a few lo outcrops intervening

Em conductor ± 210 wnt parallels

geochem — EW — ~~[illegible]~~ on south

— ± 50 so of geochem — (20 ppm Cu

back ground) EM open on West

minor cc in gossan frags — sp barite

Propose two trenches to bedrock (NS) —

± 100 m long to cross Em and geochem

— rounded pebbles indicate some cover

transported — hydromorphic or capillary

movement of Cu into cover? — partly residual?

limits of zone E-W not evident —

but definite mineralized qtzite — no Cu or Ag assay

except 3 oz in small spec CC —

needs ~~goto~~ outcrop mapping

270 NNW of Windhoek Outjo — 5-5-76

With Hein + Robert Can to Folle gossans 20 mi
SW Outjo — in Ls massive limonite — some slaggy
some boxwork — some breccia — pale yellow brown
scratch — some massive no texture — rare Cu stain
malachite — usually assoc with strong silicif —
2 dd holes cut massive pyrhot with 5-10% py
1% cpy — old shafts (50 yrs) hit sulf 5-10 mts
str E-W I 50' wide — goss resist to weather
ing form prom outcrops — drilled by Falcon.
1968 — in limestone late pre€ — strongly folded
Saw black eared fox (3) — 18" high (full
grown springhaas type — guineas — quail —
on drive from Windhoek — passed over
late Pre€ schists — granites — and
Karoo (Mesozoic sds + volc.) —
Large areas 5-10 km wide — shallow
some caliche or calcrete — and soil
Cover — occ ridge or hill out crop —
— sparse to mod shrubs — tall grass everywhere
— overall outcrop 10-20% —
Folle — IP and mag —

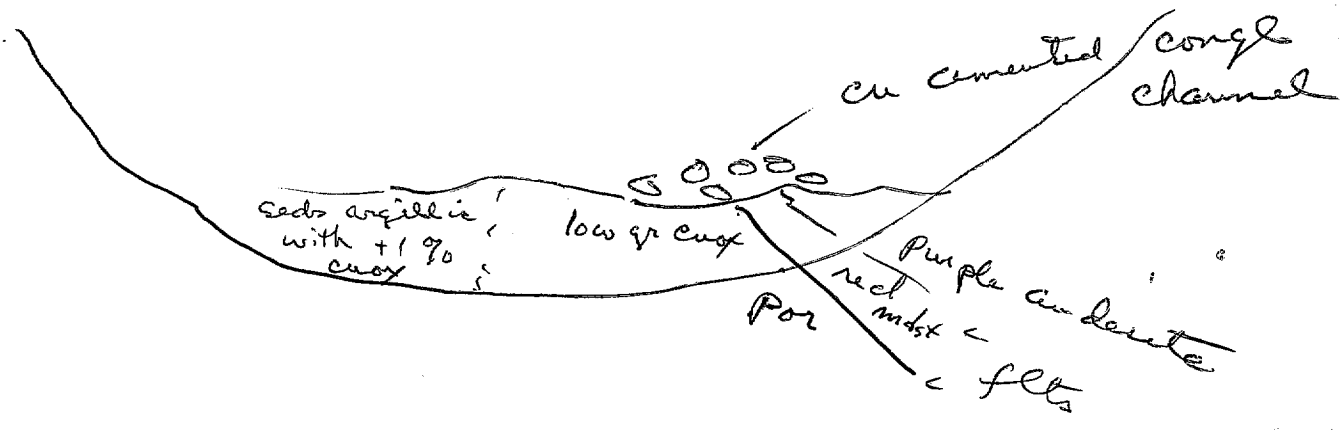
12-17-75

Sax N + S

with WLK, FTG, JRK, Lou J —

Sax X N — some dis py on first bench of leached cap — mainly remnants in arkose argillites — often nearly barren except along flt fracs — with good hematite — 2890 lowest bench (20' benches except in gravels) ~~a~~ 2910 bench — chalcocite in grains + stringers — leached ~~an~~ rock immed above contains little or no hematite mainly ~~b~~ yellow — to brown limonite —
~~a~~ on west bedding dips steeply west — N striking anticline? —

Sax X S — saw fault on S side of main graben ~~at~~ fault at contact



oxide ore body very spotty, not drilled close enough — almost mined out —
now mining 2000 tpd from each pit
recov improved to 80% ~~a~~ with ore from south pit —

(1) Summitville - 9-5-75

210 outcrops

Aug 28 - Outcrop - 8809' sampled - 1509' (26) assays

1509' - .099 Au

70% samples on .05 cut off - 1050' - .122 Au

43% " " .10 " 646' - .159 Au

As of 9-6-75 assays → 2664 all sampled outcrops assays returned — .085 Au, .05 cutoff - 1530' .130

at .10 cut off — 944', .173

have oxid .94

plan ± 10 more outcrop samples total ± 9000' -

DDH 5 - 20 - 265 - ± .01 Au - .01 - .10 Cu

1500 - more bx to bot at 3000

2190 - qm p bx - to 3000 - with 20% sericite

2400 - cpy moz frags - not in mineralization

2700 → Anhydrite - starting at 2000'

2885 - 3000 - 5-6% total sulfs

Percussion holes - 1 5/8" and 2 3/4 - plus some 3"

- 205 holes - 5428' -

assay thru 64 holes - Rec - starting on 8

9-6-75 → 223 — 6442 -

No 2 - 0-20 - .105 No Rec ~~TAHon~~ ± 100' N Annie Glory Hole

DDH 5 - Rec 45% ± 150 NE " " "

(20' NE of 13) P 14 0-10 .09 270 SW

P 12 - 0-8 - .13 ~~160' to~~ Copp Hill adit

P 13 - 0-52 - .12 300' SW " "

P 18 - 0-30 - .05 48% 120' NE DDH 5

P 15 - 0-15 - .05 34% 60' ~~NW of~~ SW DDH 3

P 49 - 0-14 - .22 73% 440' WSW of Pickens cut

P 50 0-20 - .16 73% 70' NW " " "

P 52 0-25 - .10 70% 285' SSW " DDH 2

Silica mod to st in 16 out of 64 - 64 - 49 holes

9 holes 2 [illegible] 49% rec

$$\begin{array}{r} 4000 \\ 200 \\ \hline 800000 \\ 20 \\ \hline 16000000 \end{array}$$

≠ 500' to 1000

Program - out crop Compl - except for ≠10 w of Del Norte

Percussion

all in outcrops

25 more in Ida Annie area —
10 " in Copper Hill —
60 " in Tenkasb - includes Science
Aztec and areas S + SW —

Started locating P holes in outcrop
with P 113 and PX 10 —
currently on PX 45 and P 180

Have about 3 more trench on south
will Then use back hoe to open adits.

Outcrops w of Del North portal av plus .10

Trenching — 31 - 8450' —
assays for 1372' — 8 - 20' samples - .05 - .16
plan 3 more trenches SW Tenkasb -

DDH 5 - wk min lalite to 50'
- peb dike 50 — 94
Base oxide — 94
Cordierite por — post M? to 127
Q hablite por 50-70%, qtz alunite 239
at 290 - st silic - coral py 285 - 333 matrix sul
gen tx mu - vuggy siliceous -
290 - 93 - .08 Au 2% cu
297 — qtz al no vugs v lo py

324 - 333 — .10 Au — .35 Cu — silic vug Q L
415 - 425 — .02 1.7 Ag

265 - 378 - 141' .02 Cu 32 Cu

445 - 516 — alt to M bx Q L
634 - 1108 — almost fresh - sericitic phenox - Sericite — Q L
1108 - 1159 — fluidized bx — 2 to 3 py
1174 — v sp py — almost fresh Q L
1370 - 1405 — intrusion bx — sp py - st argill alt
1463 — Q L P — argillic
1518 1642 — int bx — mod py - st argil alt
1642 90 — bx Q L P
1285 — 98 ~~mod bx~~ - Q L P - a few hair line seam fluid bx
2182 ≈400 monz - fine gr phyllic, st dis py - sp cpy - mod veining - some frgs — ? bx?
2494 - Q L - some frags - wk to m alt sp sulfs
2885 - fine gr mz? - argil or phyllic - sp sulfs anyhy and calcite veinlets. - minor bx
3000 Monz more diss py — trace cu — fracture of sulfs has por cap aspect - light gray speckled may be comb arg - phyllic - some bx text

Bx tight no sulf vugs

Summitville 9-7-75 (4)

Underground

Narrow Gauge – 320' from Portal – caved
~~40~~' – .04 – old assays

Dexter 300' " " ice
no known samples

Chandler 620' " " caved – gas
no known samples

Science 182 " " all open

Del Norte 82 " "

Iowa 500 " "

Copper Hill 239 " "

Upper Highland Mary 220 " "

Prod – 30) 7,000,000 = 230 0.2 oz to 1941 (gold mine closed)
60
100

assume .5 grade = .5 million tons milled

P drilling – I 10 hr shifts – 300' per day both rigs
plan to continue – 25 day $ 7500
6400
13900

50 holes in area from DD# 5 to Esmond adit
60 " Aztec Tank – and sw
110
30
3300

} 2 more weeks cat road work
" " on backhoe including Trench adit 2 + 1
Aztec
Bolcombe 1 2 + 3

now 5½ weeks behind in assay returns -
as of 2 weeks ago - 2 weeks behind —
as of 5th sept — had returns to July 31
have shipped July 529 ~~samples~~ (assays)
aug. shipped 1087 — no returns
probably ± 800 in sept —.

Trench returns to thru T-10
"Out crop" 210 total - assay thru "O" 35 —

13 out crops < .02 down on E (not plotted on geol map)

best au in Sp 8.00'

9-11-75

General Custer
Yankee Fork
Salmon R Idaho

mineral area 500-600' long ± 200' wide —

Exposed on dip slope ± 40° — estimated to be (silica andesite — Au Ag) — ± 100' thick early day miners stripped off surface and drove a few adits — silica andesite remaining runs ± .02 Au, .3 Ag — on of 20 outcrop samples — .03 Au .5 Ag on ridge a few 100 feet up hill — This appears to dip steeply ~~N~~E — as ind by adit workings at surface nr vert — width ± 50' —

Assays not all returned by main zone limited to ± 100' by evidence of wkly min andesite in ~~one of the~~ an adit — will be sampled to make sure —

Silica andesite resembles Summitville by alunite looking.

Grade marginal and potential tonnage limited — 5-10 m.

property 35 miles up Yankee Fork of Salmon River

Rapids Project
Noranda Dist - Quebec
8-3-75

With Cha Cabolins and RLB - to prominent outcrop north of Noranda Smelter - rhyolite with fragments up to 1' dia ("mill rock") rhy bx or agg - Then to cheskirk group - chlkd outcrop of rhy agg - Then to Mobrun - no outcrops - ≠ 70' cover no develop. 3 mill .69 Cu, 2.18 Zn .05 Au .62 Ag met problem - ½ mill tons .55 Au -

Then to Silver area - rhy bx with py in shaly beds in outcrop - Then to outcrops on E side of road rhy bx -

Then to west ~~on~~ MacDonald - 300 x 600 out crop area - massive py - some flow banding sp sph. (py) - rhy or? - prod 1 mill tons, 30,000 tons Zn 2000 oz Au, 5300 Ag -

P-2-75

Drove with RLB from Timmins 40 miles east to Tillex project - propin of townships (equal to 3) - prospect in SE part of Currie - SE NE
Checked andesite footwall ± 400' west of discov hole (no 3) - cut by 10' dike with blobs of epidote - Dick says characteristic of N. striking dikes -
~~After lunch~~ also check andesite outcrop along road - damp - ~~[illegible]~~ ground mag high -
After lunch - checked drill core (see notebook) deposit as so far known 1100' long ± 50 - 70' wide .97 - 1.5 - 1.7 -
6 ovb holes - in discov area - 99 in all within three townships.

7-31-75
Buchans

Meeting - Don Baker (Price) - Eric S. RLB, PNW, JRK - Jeff Thurlow, Takeo Sato

Clem why post min - 2 horiz of ore cobbles bet Clem & Lucky st. - target obviously low topo low - if beneath diabase - 3000 - 4000 deep - at least part of bx with ore frags on top of diabase - if ~~clean~~ mclean grade 1/2 mill tons - if accessible from mac lean workings - if lower grade - 4 - to 5 mill the odds are that it will be lo gr.

- So of target 1 - (hole 17 30) sample strg alt why run 200 Au

possible N steep cont of Roth mine - not term by workings of drill holes.

So of Lucky St - ore hor with ore frags beneath So dipping fault - possible ore beneath fault or above it

only basement andesite outcrop - in flr of Oriental

Area 1 - 5 - 2000'
2 - 2 - 1100
3 - 5 - 1600'
} 21,800' - 257,900
83,200
174,900

6400 13
1920
6400
6320

6400 14
3200
6400
6400

Tony Kryslak – Price
Don Baker "

7-27-75

E 11500 Section – Thru oriental looking W
logged 70,000' core ± 80 holes
post min fault bet based ark – and – and min
up to 140' thick fault

Sec 7500E (old Buck ore) – 2 faults –
on outcrop along river – underlain by fault
stuck in bottom fault –

Sec 5000E thru Lucky St
fault under to N – cycle 1? no depression

① Drill target SE of air field in rhy to E of andesite (1900 to 2010 deep)
② NE of oriental to hole 2772 – ± 1200'
③ N of Lake 7 – channels running west from Rithm
split toward Lake 8 – ± 1400' deep –
④ – possible cont. ore being down dip to North from
Rothmere
⑤ Down dip to S – Lake 2

hole 295 – ± 2000 N of Oriental elk
fault contact (rhy tuff and arkose) ± 1235
1179 – 1226 sheared min tuff alt. silic (intermed ft w)
± 90% NCOV – of core

Jeff Thurlow 7-28-75

(76) ← on map

hole 2367 — ± 1000 Oriental shaft.

with JRK & Pulcher to Oriental no 1 Glory hole
broad shear dip ± 55° N on S side of hole
underlain by ark ore — ore in hanging — Then
to Buchanan rim — congl with ore & barite boulders
~~in rhy~~ assoc with rhy — fault contact — hanging wall
of ore exposed, also fault contact.

180 — congl — ark etc boulders — been called hanging ark
188 — contact with (rhy por) crystal vitric tuff (porphyry)
400 — Cryst vit tuff — a few frags — scratchy — some chl
438 — fault — calc clastic — ore specs as drag
446 — int mod ftd bx — sélst — pumice frag etc
± 3% sulf — a little stwk —
490 — barite frags
541 — sulf contains in bx 572 sulf
600 ~~andesite~~ 607 fault — then barren arkosic conglom
631 bottom

hole 1662 ± 4000' NNE Oriental

113 — cryst vit tuff (porphyry) dark col ~~matrix~~ — frags
160 — fine ba dis — ~~cryst~~ vitric tuff — post mineral
266 — Diabase 377 — qtz xl tuff
616 — ark cg — ad some tuff
712 Rhy — fragmental — 801 dittto but no frags
877 vit tuff — 1000 — rhy — 1050 — stwk
1320 pumiceous rhy 1400 trace gal on sph — also 1500
1640 — mini rhy — 1658 — footwall and (not basement!)

1062 – ≠ 2000' N of Oriental

900 – expl bx rhy – to Sulz → 983

1040 – poor ice – fault gouge – thin ark & vol

1080 bottom – barren footwall

940 ≠ 1500' NNW Old Buchans

60 – andesite bx – 1040 andesite

1003 – 1500' N of Old Buchans

1055 – andesite (suppl Cy 2) flow strat – hw structure

variable texture

1300 and bx – 1372 – poor recov – fault to 1400

and below, 1500 rhy fragss andesite – stringers

pu pb zn 1602 basal and. zone 1400 – 1600. 200

bot 1642, and

963 1000' W NW old Buchans

500 – 600 – rhy bx

486 – fm and + diab to rhy

753 to 820 – stwk min in rhy

10 – 1120 stwk min in intermixed fine bx (and) – sild but v sgth vein

1120 – poor dike – granite related – the andesite

1406 NE Lake 7 – Target area NW Lake 7 – 1000 – 400' above diabase (< 1500')

≠ 700 – sl sst + rhy – at 844 fault

915 – tuff with sed frags

1162 sl sst to Rhy pos (frag tuff)

1310 – 15 – one sl sst in Rhy – fragmental bx or cg

Previous frags fragmentally in stwk

Tony Pryslak — Price

→ 9322 ± 1000' N of 1406

1196 acid dike — reddish phenox → 1400+ dark tuff

→ 2210 600' no of ~~2402~~ 1406

±1000 — ore clasts in cg → also 965

→ 9322 ± 845 — sul clasts in cg. bx — on rubble flo 7-29-75

± 900 — " " " " " " "

2320 Clementine

± 100 — brown rhy por

± 200 — diabase

± 300 — vole bx

± 350 diabase — 430 - diabase — 477 vole bx 500 bx

800 rhy — (920 - 965) — ore frags — ~~and sul in stress~~

in bx — 980 — more tuff bx - no ore - andesite —

Look wl sericite below.

1000' - 11/ft —

Evie drilling holes SE edge Clear Lake

2899, 2900, 2897 bet 1000 - 1500

0-1000 - $11/ft

0-2000 $13/ft.

KLB, Ed Perkins, + L.D.J.

7-30-75 — AM drove 40 mi to Floyds river — where he gr boulder kicked out bench gravel by dozer about 40' above river — bench overlain by subrounded boulders ± 3' dia — ~~on~~ in turn overlain by stratified silt and gravels — see well rounded quartz pebble or cobble — some py in qtz cobbles —

7-16-75

Bisoni Fl prospect

with JJC + MpB — 6 hr drive to Eureka
— to prospect 13 miles by road SSW — first
to SW edge of prop — inspected trench — qtz mica
veins in ls just below qtzite — DDH ? no.
proceeded up to US Borax hole locations —
then on up to trenches on ridge crest —
Then to trenches on NE side of ridge
in ls underlying Eureka qtzite —
Then to core storage in Eureka
best CaF_2 generally in dark gray blue ls
or dol — some qtz ~~mica~~ mica veins
but many 5' runs of ± 10% CaF_2 in dark
ls with almost no visible CaF_2 —
Burt Morrison came over in charter
310 Cessna — (98.00 per hr) — 1½ hrs from SLC
~~we~~ Back to SLC in charter —

more ground on SSW needed for
possible ext of fl. also for poss dump and
tailings room

Assessment work ($6000) should be
spent drilling for met samples — also
half cores should be split to check assays
and for met samples —

Possibile better fl in certain bedding horizons
— that is some beds may be more favorable —

11-13-74

West Empires Cu prospect

Field recon with IRK WLK —

Hiked west over cut thin bedded limey seds and up canyon thru bx pipe (± 1000' dia) composed of limy blocks, mostly thin bedded lightly packed with occ. subrounded porphyry unaltered boulder — general barren aspect but occ. blob of py — some on fractures — pipe apparently cut by highly pyritized por dike — pipe appears in incipient stage of development — minor milling actin — resembles Maya's fluidized "zones" at Brown mt.

± 2000' south of pipe — porphyry copp min alt in north dipping K seds with por dikes. zone ± 1000' x 2000 elongated west-east — ± 5 drill holes — ± 500' deep — indicate average .12% cu primary — leaching 10-20' —

Conclusion: min-alt zone to small and too feeble in larger zone including pipe to constitute a valid dup target — In discussion with WLK — recommend property be dropped.

JHC

'73 2.9 [illegible] 6.4 zn
'72 2.9 4.6 6.2

7-13-74
Anvil — Faro

Newt Cornish — Mgr — Bob Gale + Roy McMichael

10,000 tpd — mill cap 12-000 tpd —
W/O 6:1 — "6 weeks ore" available ~~open~~ - tight —
pit designed on 5% comb cut off — 9% comb av gr.
now can cut off on 2.5% comb —
20 freight to Skagway —
mill — 52% zinc con — 70% Pb con — 85-90 rec
cost — $1.00 per yd — 3.4 ton mining —
6 wabco 120 ton — 1 15 yd shovel — other
65 ton + 5 yd shovels —
Blast holes 20'-22' — ore breaks fine — benches req
— ± 40' — slope 45° — bench failure
on north in monzonite —
ore — granular — grains Py in sphal-gal —
medium cse x1 — fine gr pyrr — 6-7%
Garile — host soft schistose phyllite
— winter — temp to 45° below — some
frozen ore stockpiled also some oxidized ore
ore — tabular mass warped up at N+S ends. flat dipp
payroll 450 —

an ? (.01)

2-26-74

Black Mt. Inc
Kennon Mine

Jim Scipel res mg + VP
Pete Morton ~~mine supt~~ Block cave consultant
9 km by rd down canyon so of ~~Bangwet~~
Bagés — 2800 mt tpd — town of cave
area — leached cappin in float — some ore (sulf)
exposed — leach cap + 200' Thick on hill above
— ore dio with strong fine gr bio — cpy in
Thin qtz veinlet and as discrete grains — numerous
dikes some regular some irreg 100—200' Thick
cause dilution of .5 to .6 — down to .4 —
dikes break ese — some sorted out at
grizzly & before ~~co~~ primary crusher —
(± 5%) — planned 3rd level at 600' depth
Cave angle 70° — 50° — is part controlled
by faults — map all workings — dikes & faults
degree of jointing — helps estimate density
of holes for undercut — { most ore at
draw pts minus 2" — get very little ground
take any lot — some drifts underbroken —

Mankayan — core No 2 hole — 2850' —
lot 1000' .33 Cu .3 Ag .016 Au — post min crystal
tuff ± 200' — 750' bounded by faults — Then ser-clay?
pervasive alt of andesite(?) — orc dis texture —
very sp to mod dis cpy — tr bn — assays show
As. — probably some enargite — most cpy
on seams — qtz seams — very Thin — no qtz
flooding no qtz in andesite — phyllic zone?
750' to 1750' — .1 to .25 Cu av —
no 1 hole 400' distant shows similar interval pt
in die zone 500' Thick dipping 60°-70°

pervasive magnetite

at Bangwet to + Thanksgiving where 100 Tpd — .4 Au 3 Ag — .7 Cu .10 Zn
Eddie Henry

Geol Schuler Sampson Pete Morton

West Silver Bell Notes
Aug 21, 74

With WHK, FTG, SRD —

Failed to find small altered outcrop of cat ~~not~~ reported by Briscoe - Richard — minor amounts of dis limonite after py - but unaltered Tcr (intrusive? - gray felsite) in wash to ~~west~~ East - so no sizeable zone possible.

Continued south W - wk alt in tuffs in wash — C Coglin Ranch Fm -

Checked skarn with Cu at old workings -
Cu + sk associated with E-W near vert shearing in ls which is fault sliver in Cret Ark.
- Small and poor - and diabase intrusion to SE
- no alt. —
Skarn farther SW is also fault sliver.
FTG. says this is hydrothermal skarn in contrast to contact skarn in ls at granite por contact Red Hill ≠ 2 mi NW —
To - arkose + SB andesite conglomerate interbedded in contact. with Tcr - intrusive?
To exposure of Tcr - alt - pyritic limonite - and near by location drill hole - hit 5-10% py a ≠ 50' —— expl hole ≠ 2000' WNW hit wk to mod alt in Tcr — will be deepened to hit sulphides — Hole ≠ 5000' beyond (North) hit unalt SB Fm.

Memo ~~for~~ T J Collins

Nicolet Valley

Quebec

A ~~Our~~ trip to the ~~the~~ Nicolet Valley asbestos deposit ~~was made~~, located 20 airline miles southwest of Black Lake was made with T.J. Collins and Dick Brown on July 25. Two centrally located surface areas ~~for~~ which provided bulk samples for mill testing were ~~taken~~ ~~were~~ examined and a brief inspection made of a serpentinite-schist contact ~~on the~~ exposed by erosion in a creek on the northwest side of the deposit.

In the sample pits and in the boulder float, mosaic patterns ~~were~~ of short cross fiber and narrow shears containing slip fiber were observed in the serpentinite ~~and slip fiber in narrow shear zones~~. Mr Brown brought up the possibility that the relatively ~~high ratio~~ abundance of slip fiber compared to ~~the~~ cross fiber may be related to the absence of igneous intrusions cutting the serpentinite. ~~The Black~~, noting that the Black Lake deposit with granite and syenite dikes is relatively high in cross fiber ~~and~~ content.

Limits of the deposit have been approximately ~~defined~~ outlined by magnetometer surveys

July 25
Black Lake

With JJC, RLB & Nicolet Valley — checked sample pit — some cross fibre 1/16 to 1/4 serp — some mosaic type — ± 1/16 — checked pit at adit portal — lo mineral — climbed to contact on NW — no magnetite in serp
may anomaly extend SE across river
nicolet — no dikes — as at Black Lake
may be reason less X fiber at Nicolet —

To National — N ~~W~~ of Baker asb. pit
Serp-peridotite strike NE dip 55 SE — shale walls
foot wall uniform — hanging wing — ~~as~~ mainly
slip fiber — ~~some~~ better developed along
foot wall side — X fiber up to 1/2 — but
~~at~~ very little or no mosaic —
mining 4500 tpd — 5 & 6 day week
W/O 1.2 — ~~45~~ will increase with
depth — ± 1200'? ult? —
magnetic sep being installed — will
reject 30% — present grad 6%?
fiber — 70%? slip — also 45 + 6 —
no intrusion —
45' benches — bottom level — muddy
— water seepage — have drill holes in foot wall
to relieve water pressure — reduce poss wall
failure —
70,000? tons fiber per yr

Oct 2 - 72

Buchan

Review of maps - 206 Bradley holes — Eric revised geol map on holes drilled to prospect contact

copper sulphides hit in area so of Little Sandy lake ½ mile no of highway - (with Brad drill) plan dd —

mauvaine phyt cpy in core from Skidders brook - in andesites and tuffs - bedding 45° to core - holes at - 60° —

on short moves Bradley drill 7 to 10 holes in 10 hr shift. -

NE striking conductor (EM) in Wileys lake — cuts across altitude of volcs. as mapped —

Beechers Oct 3

Am – Office
PM – to area west of Lucky Strike by pickup – Then by tractor to Bradley drill site – mowed down timber (up to 8" dia) en route
John Glover sampler eng (geological eng)
Reverse circul of water supplied by extra tractor – 10' wide –
Drill 10' x 18' – 15 tons – Longyear hydraulic head – tricone rotary 3 5/16 dia – little or no return in first 40' of overburden – fair return in bedrock (some sludge still coming out around collar – drilled 25' hole in ≠ 30 min – set up less Than 5 min – ≠ 25' mast – tracks ≠ 3' wide rubber with steel bolts – 4 rubber tired wheels inside tracks –
Saw 2 holes drilled on IP anomalies east of Lake No. 7 – minor py in fragmental andesite in first – dark aphanitic rock with epidote – no py in 2nd –
Outcrop mapping in progress Wylie Lake area –
5 drills? running west of Sandy –

Clarkson Mod well

Oct 4, 1972

To Little Sandy Prospect —
Hiked ½ mile north of hwy east of Little Sandy creek — py - cpy in sludges from Bradley drill — no geochem response (very minor) — holes drilled on IP anom. — Andesite. Subsequent EM shows anomaly also on adjacent geochem anom ± 200 ppm Cu 400 Zn — in timber — one outcrop of dacite — numerous qtz phenocrysts — some py staining —

15' cover →

Pm — office — checked proposed diamond drilling — and map of Brad holes — 45 west of Wilcox lake, all anomalous — ± 1½ SE of Clem ville — drilled on EM anom? — total in area 60? — 70!

Sergio + Kathy — party starting at 8:00 pm — Thomas + wife — mill? metallurgist — mrs Hart — Mrs Larsen —

40 min by Beaver up — Oct 5, 1912
50 return — ± 100 mph

By Beaver to Pilleys Island — JJC
Robt Lacy, Dick Brown — Ken Larson
drove up — saw 3 bull dozer pits
first showed a few lumps high gr pb zn
in fine gr py — ± 20' Thick — dipping
± 30° S — mineralized horizon in
agglom or fragmental volc — noted
collars of vert drill holes —
gen strike easterly — ~~and a~~
Silurian — overlain by SS
Containing frags of volc —
May be Kuroko type but deep
drilling (± 10 holes) failed to hit
much ore grade — and this
indicated by pit exposure.

Hiked along shore — observed
pillow lavas with pyrite around
pillows also in cross cutting fracture
farther on 5x pipe (50' dia)
made up of ± 2' dia frags
including large frags of massive
pyrite (drived from Kuroko bed below?)

By Beaver ~~to~~ NW to Betts
Cove — ophiolite — Moho —
transition from peridotite to Gabbro
— saw "sheeted dike" — graded
bedding in ultra basics — serpentinite
along fault — saw pecrolite — pillow lava
above

Oct 6, 72

plotted Brad holes —

Examined core from 202 DDH located UG — ± 1500' west of Luck Strike —

Hole cut ± 500' of low gr Cu pb zn in dark green to black tuffs — some fragmental — some porphyritic

qtz veining with sulphides as blobs stringers and grains — varies from ± 2" veins to very fine network — or stockwork — some ore grade —

bot of core pulled at 740' — about 70' below zone shown on section — shows stringers with some sulphides — Ken says stringers continue to ft wall and — there cut off abruptly — fault? — zone as shown on section shows extent of appreciable Pb Zn

at 740 some massive basalt?

Oct 7 JJC – RLB

To Oriental — conglom dip 45° N — alt dacite tuff in footwall — Dick took geochem samples — later to old Buchan

Bob Seraphim — consul geol. July 18-72

20,000 400 hp ≈ 120 mph ≈ 250/hr

By jet Ranger (Bell 602 B) to Minto 140 miles at 120 per hr. Roy McMichael in chg — town of trenches — cpy and cop pitch — as + mal in foliated grd — barren gr or grd in walls — cu in (bn cpy) in grain and small pod, with bio + K feldsp — erratic descont zones — almost zero py — narrow descont zones of potash — reserve ble in this respect

Trenches cost $1.80/ft drilling 20.00/ft

por cop potash Zone — no continuity establish by 10,000 ft of trench and holes — ft

Very poor potential — Conglomerate in the hole — Cert? with Carnach ~~to~~ andesite frags

Barry way — geol.

By chopper to Williams Cr. (Strauss) 35 miles south — cu zone ± 100' wide — 3000 long similar to Minto but more biotite — malachite in trenches — granite wall rocks — ± 800' oxidation no secondary cc — 1200' long for ore — 1.50% Cu — to 1500'

TJ Collins
Cole
Roger K

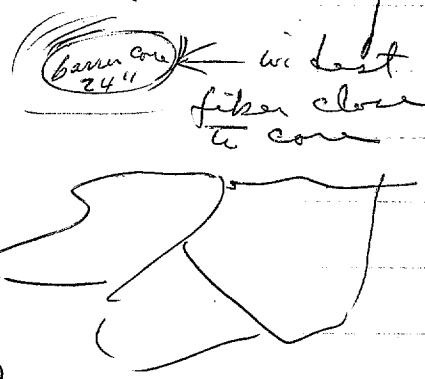
Shasta — July 5 72

AM Review of maps — in office at Shasta Royal — inspect core lab and sample ~~plant~~ plant — all King man — 2½ hrs per sample 20-30' core 4 lb ~~fat~~ NE
PM — to North zone — DDH ~~8~~
South zone DDH 8 — stopped at 5 92 — trace of fib — Serp — outcrops — rubber fib — mostly < 1/16 — ± 4 — 5 %
ME 3 under "long fib" pit — $7.00 US 11.00 in bulk MSS under other pit
North zone — much friable — crushed — poor core rec — in ± 4% fiber —
Most samples obviously high graded —
north + south — 100 — 200' up to 300' wide dip ~~—~~ east 50-60 — looking uniform on So. —
whole business marginal —
± 10-15 mill tons to 400 — 3, 4 to 1 strip

Sample plant $40,000 — incl. QST —
as per drill shift (moving ex cl) 17'
at Lunity ± 40' — so as at ~~the~~ Map
Eddy ± 10' per shift?

July 6th

By car to Trinity — no 8(9?)(vent) drilling
all holes hit dio ± 1.580' dept
dio dips southerly at 40°
mike est (main zone) at $6.00 rock
- fiber feels slightly harsher than Eddie
occ ½ to 1" Composite —
magnetite bands common — but
doubtful that either Trinity or
not Ed dio amenable to mag
conc — "almond" pattern



By chopper

± 2000', long
500' wide

to shear ridge south zone — sparse
narrow fibers — so called crackle —
fibers at rt angles to main stringer

walked down ridge to no zone
lo mineral — but smaller —
drilling 2nd hole (loc work)
both very dim prospects

July 7th, 72

Checked over Eddie drill holes — sections — some poor rec — but also some 5-6 oo with 90% rec — very likely appreciable fiber loss — partic long fiber — but not critical to evaluation — zones too narrow (usually less than 100') — possibly 70' average — Taking into account mining dil — no reasonable poss of commercial op —
Von Blanco reviewed various geoph — results —
PM — by chopper with Ross Smith to China Mt — around 7500' elev — a few remnants of snow — whitish or bleached weathering of serp readily visible from air — classic "almond" type occ. 150' Thick 1000 long — narrow fib — 3% — $2.00 almond cores — brown — wk to mod serp — surrounded by strong serp (black or dk gr) with fiber — surrounded (the better zone) by lower grade — well exposed —

Better zone forms bluffs — relatively resistant (apparently) to erosion — but down the ridge to East — whitish outcrops (fib bearing) occur in saddles — Mt Eddie top noticeable only by roads and cuts —

Oct 8 — left NY 8 PM — arr Oct 9th 7:30 AM —

Lisbon — Cabo de Roca western most point in Portugal — then Cintra for tea —

Oct 11,

Left hotel Lutecia 9 AM

Drove S from Lisbon — Thru Setubo. Acasar on to Grandola to Aljustrel — Portugal produces 600 000 t Py per yr with 1% Cu — Spain prod 2.2 mil tons. Port reserves 200 mill Spain 500 mill — Aljustrel open cuts — pre Roman — 2 or 3 op shafts — all ore mined underg — saw DD working on N side fault displ on dike — 203 km displ — 18-20 m tons N of fault.

Cont S thru Castro Verde — to Vila Nova — from Lisbon = 300 km.

Sin Platon

Oct 13 –

Vila nova – discussed py belt – bet Santo D and Alustrel – volcanic present but ore are known – poss recon in 4 diff river channels crossing belt. Rod drew profile of Rio T – showing stk wk py in between synclines with mass py, pointing out that stk wk was poss epigenetic, while adjacent mass py were syng.

proposed recon bet Santo D and Ajustrel – check in geol interp and also geoch sampling with object of det sed horizon as those below – or might overlie – the ore bearing horizon which is the Tuf de Mina.

14th of Oct – drove from Vila nova thru Faro to Huelva – hotel Luz there John Stang + Mary – after lunch John reviewed his maps of Huelva – John says most of show on Spanish geol maps as Dev are phyllites of Carb age and thus could contain sulphides – It was stated that

The Huelva dist has produced over 5000 yrs ago 5 million tons of copper sulphide prod began 100 yrs ago
tight isoclin folding with dips 60° N — in addition to the folding thrust faults parallel to trend of folding — RBS proposed rock chip sampling to define possible areas of blind ore occurrences. Strong maps 1:50000 or 4000' to inch. ~~G~~ al G believes that the manganiferous nature of the silic sedi or indicat a deep sea environment —

Fri. oct 15 — Huelva — picked John St in Valverde — drove to Rio Tinto — loc 70 NNE of Huelva — enroute N stopped at outcrops along hwy — Devonian phyllites overlain by acid volcanics with porphyritic text + qtz phenocr. farther north saw phyllites overlying volcanics. a few inclus of phyllite in vol —

continued north to mon mine in cherty jasperoid form on contact bet the carbonif sh and acid vol. turned back and drove

to RIOT - met Dick Read
geol — he emphasized dis
min forming funnel like
shapes beneath the massive
sulphides. drove around open
pit — La Colorada — 10000 tpd
6 days week — mill is by flot —
saw dump cone to Huelva smelter
various types of gossan incl what they
call good gossan running 2 gr
Au + 44 gr Ag — This is rubbly
material with jasperoy material and
much clay — doubtful if derived
from massive sulphides — but may
be — that is a residual
accumulation — also saw gossan
on the edge of earlier most pit —
slaggy texture (from massive sulf)
on one bench saw dissem cu or
1.2% cu — with cc or cpy — total
sulfs + 3% — ave grade small
.8% cu — cut off .3 to .4
expl drill holes 50 m centers &
subsequent 25 m centers — on
add'l comment
road but volume — follow structure
saw La Mina de Concepcion

La Colorado — on x section (5)
same sam pattern of V shaped
dis sul pinching out at depth in
acid vol — we also saw patterns
of ore with consid interior wart a
(.1% cu) — sul of entire
area .4 to .5 cu — mined
.8% dis beneath mass in sulf

Sat oct 16 — drove north
from San Platon small adits show in walls of
open pit — Reed Sprague & Jay in
left by cu for mazz — we proceeded
to Sa Miguel — glory hole —
mass in pyr — flat base to oxid
— 40 m deep — prod 1000000 tons
starting back 1900 — to 1960 —
range 3% cu to 1.4 at end of op.
deposit entirely in and vol — locally
sam bleaching to lt gray — mostly
dark green green — with qtz phenox
— dacite —

end of open pit (west) — pattern
of stwk — mass in sul surrounding
greenish angs to rounded chlo andesite
frag — similar to text depic
by Read at Rio Tuto in Tharsis

Pyrite, according to "Py de Huelva"
run only a few 100s cu —

Hunt + prof
Banabach maps
~~Porto~~
Roa in Gorlovia (fine
Rio [illegible] Douro)

Monday Oct 11
Villa Moura - Portugal

Left Lisbon 9 AM - JJC + A Geiaike - Drove south over Tertiary seds in thick fog - relief generally low - max elev 500 mts - arid - spotty dirt cork oak - pinion pine - olives -

(Tejo river Bridge)

Saw Lousal in distance - von fault (NW st) from Tertiary into Carbon'f (also Dev?) - saw tight folding in volcs (andesitic flows - thin bedded, water laid tuffs - from 2 or 3 shafts

To Alpustrel - (prod - ± 400,000 tpy - rubbly red gossan sev. mts thick - ~~to~~ / especially flinty - in part - old opencuts (± 10-15 mts deep) worked (for Au Ag - native Cu?) in pre Roman times - on north limb - py recently disc on so limb - but dips away at acres vert side line -

Also - ore disp on dol dike - 3 Km shows up in gravity anom -

Drove S. to Loulé - into mesozoic - unconf on carb shales - Cu ox + Mag in ss - Trias. - veg vines - farming etc - olives - figs - citrus - cork oaks?

To Vallamoura hotel

Oct 14 —

Drove from Ulla mourc to Huelva — ~~Hotel~~ Luz-Joy May there — J Staargaard layed out map, photos in hotel room — described rocks of Huelva dist — ~~a~~ interp some synclines as ~~ab~~ anticlines or vice versa — interpret Dev ~~in~~ shales in SE as culm — or cover — probably not correct — according to Geiseke — considers sulphide occurrences generally associated with faults. John shows volcanics & ——— deposit area as passing under culm, but BEK — mapped as fingering out in Devonian — ~~Dev — characterized~~ Increasing meta — to North

Oct 15

John S joined us at Valverde — drove north — stopped along road at contact of black carb shales (Dev) and rhy volcanics — strong folding and faulting — contact (vol over sh) appears conform — ~~Foo~~ yds N, contact (sh over vol) irreg — possible intr — frags shale in volc —

Continued — saw pillow struct in andesite — ~~Crossed~~ min — over culm — graywake above shale section — silica manganese on contacts with andesite — MnO mine —

Cont

To Rio Tinto – Dick Read showed us plan (old) and section – diser min passes upward into massive

dis ore in chloritic zone this surrounded by sericitic zones (Read)

To cerro colo pit – on bench running 1.2% cu – dis cc in rhy – andesite weak min –
– "good" gossan 2 gms Au – looks residual
– much silica + clay as well as iron –
saw some slaggy iron ox after massive py on old pit edge – some sph bxwk –
Oxid ≠ 50 mts –

Oct 16 —

Returned to Rio Tinto — to old Py mine
in canyon in tuff? on or near contact with shale contact
oxid +25 mts — zone stks west then
sharp to NW — Thin layers — in Py
probably tuff beds — ? — small tonnage
total — Rod and Jay left
To San Miguel — on contact
with shale and wide — andesite (qtz phyric
dacite) — some alt to lite gray —
oxid, sharp base — ≠ 25 mts — sulph
in face of open pit in stk wk mozaic similar
to that described by Read in Rio Tinto
prod / mild tons — sm cu au

Oct 17

al G drove John + I to Sevilla —
met BEK — by Charter — over Riotinto
and Aznalcollar — flew east over
— — — to Murcia
by car to ~~an~~ Puerta Mazarron —

Oct 18

Review of map & section —
San Cristobal
over surface — visited drill site IV & 4

Oct 19

Check over Drill core — Then Cab Hierro

Zone II

Mazzy – hole 4 in Talia – 60 western slope of Perules hill – will cut across N trending reticulated zone – depth 300 m.

State Reserves – Huelva Dist

Tharsis – (TCO) reserves 100 m nassin Py – open pit – plus poss add'l 100 m – 45% Sul – .5% Cu 2-3 Pb-Zn minor Au Ag

~~Di~~ German, (DKH) – roast, produce acid, then leach Cu from iron sinter. Pb, Zn, Au Ag recov by complic hydro met – remaining sinter pelletized to high gr iron ore DKH pays only for S and over .7% Cu –

Mining concentrated along narrow fissure - st. NE dip NW - no sulphides on dumps - continued S ½ km - recon over altered ls, schist - princip vol -

Oct 17

J J C A/G + I drove from Huelva to Sevilla — took charter with Bruce K — to Rio Tinto Then Aznalcollar — and on to coast for lunch — then to Mazzarron — The Spanish coast of Murcia — met by Cecil von Hahn — and Frandy — to "camp" at Maz — ≠ 40 km

Oct 18 — Puerto Maz: drove to Maz expl off — reviewed maps — plans — 3 drill holes in bx on Cabezo Cuthbal — then to out crops — st kwk — in acid vol — intrusive — vein matter sil in small bodies bx wk and 1% Zn — 1 Pb — ½ Ag — in oxide it appears That not much more was present in sul — lead should not migrate far —

drove to site No 4 incl east at 166 m in vol with sp dis in py — late recon over Cabezo del moro — Maroz les underlain contorted schist — also saw dike or pipe (pebbles) cutting lis limestone

Memo for JJC

Mazzaron Project
Murcia ~~SE~~, Spain

~~Three~~ The fourth diamond drill hole was in progress at the time of our visit (Oct ~~18~~ 18) to the this Project, located on the Mediterranean coast of southeast Spain. Three holes had been completed on the principal objective, Cabezo ~~Del~~ San Cristobal which

-60° M-3 — stopped at 345 m
Subs at 100 mt, 106? " -2 — " at 286 m nine old workings
Von Hahn — mapping zone 2

		bot int	Pb	Zn	Ag
M-1	4-1 — 176	- 102	.97	1.65	13

M-4 — lost at 233 mts — just short of Talia zone

M-5 — drilling now to cut Is-Hol contact

Tok Junct. File: Tok - Alaska

July 22, 1971

with S.A., JRW, W.A. - by car to Chicken - then by chopper to Eagle asbestos - enroute mod deep river canyons (goldplacer terr.) numerous expansion BR - a few py zones Eagle outcrop ± 200' wide - 1000' long - N 15 W - chys in serp - ± 6% - up to ½ inch - ~~cut~~ weak on So end. - Lab: good (their) qual - Group 4 - good filtration prop. - Est - 3-4% - over all - possible 10 mil tons - assuming 1000' x 500' x 100 (thick) - Question: are majority of asb dep non commercial due to small size?

Back to Chicken Camp - by chopper to Duval prospect - color anom above + west of Rein Camp: qtzite metaseds with dis py - drilled area at camp - then to silt by b rec area near border - in I aplitic rock with qtz eyes - 13 ppm platinum - minor lamprite - plus dark min - resembles spec but scratches grey on blk and non mag - met car on rd to Tok -

---

Drove to Fairbanks - ✓ 2 motor 737 July 23 - fly to White horse - charter Cessna 406 (JRW to Anchorage) to Watson Lake - Sportsmans Lodge

file: Dease Lake

Watson Lake $200 per hr July 24, 1971

Charter Bell Jet Ranger (370 hp - cruise up to 150 mph wt 135/65) —
20 min to McMillan - landed on "mine Creek"
very tight — thin bedded quiz + siltstone — bed
repl pyr sph gal - faults, deformation in minor
altered zone — repl on structure — not stratiform
1200 x 400 x 20 — ± one mil ton 15% comb.
and 2 oz ag — possible cont SSE — several holes
~~to~~ 100' - no BR — glacial or gravel terrace —
ammin out crop ½ mile SSE —

Charter Cessna 180 to Dease Lake — Emery
Stayed in Watson Lake —

With Mike Lancaster to Corbett claim east side
of Dease Lake — generally short fibre - ± ¼" —
in Serp - large out crop area — ± 2% - 1200'
by 500 — thin isolated shows — possible 5000 x 1500
Serp body — mag (ground out line) surrounded
by seds — 15 - slst - qtzt trianic — 300 gam
back — 1500 on Serp — fibers in soil below out
crop that looks almost barren —

Boarded DC 3 — to Scud — to Smithers
Hudson Bay Mt — Amax — color arm below
glacier — To Vancouver —

Mar 14 — 1970

arr. St Louis 2:45 PM — with JVD — drove South via Bismark to Flat River — passing numerous old lead mines — big chat piles (jig tails) near Flat River — continued on to Ironton — just south of Pilot Knob — Hanna's new iron mine

Mar 15 — Sunday

Drove with JVD west + S to ~~Viburnum~~, Comm Co next to Amax - Homestake ~~Mt. Tolo~~ Magmont and Dresser) ≠ 3,200 tpd lead ore — ± 5% — ~~the Amax Homestake~~ mill and smelter complex — next to St Jo's west of highway, site cleared for slaff (Brushy Cr.) Next to Fletcher, St Jo (south of W Fk.) then back to West Fork. Reviewed district map with Vance Green also sections — discussed expl possibilities — Two second. project — Delaware and Cold water. West Fk. 2 mi. long — 200 to 1000' in width — 4.5% Pb .7 Zn (?) 15 mil tons varies from 5 to 40' Thick — av 25' — flat ± 1000' depth — ore closely conforms to bedding — ~~above~~ upper Bonneterre — but above, not in, reef dol. bed — DD cost 4.50 per ft 1500'. ore in general area betw. ls on west and dol on E no collapse structure —

Mar 16 — Mon

to W Fk — review of ~~plans + Sec~~ mid continent research — ~~[illegible]~~ (firsts checked over core — W Fk — took spec of ss — reef in dol — ore in brown calc arenite in ± 50' below top of Bonneterre ore in Davis Sh — potash ord — cherty + silic in part — dense tough dol with numerous sol cavities — Gal + sph appears as replacement of dol, occasionally blebs along fractures.

Review of Vance Greens maps on area in N western Ill — facies change, dol - ls - arcs around ± 50 mi W of Peoria to 50 mi north — two water holes (area 1) → show fair ~~sp~~ sph and py — (± 2% Zn) in ordovician (area 2) → N E Mo. — westward extension of similar lithologies need more research of cuttings —

area 1 — 1st, check surface and land status —
~~[illegible]~~ 2nd propose 3 fences 5 holes each
1500' — or 200,000 — plus prop — 250 000 total
Met Bob Paul — Mgr. Glover at
dinner. Snow started 3 PM —
Mar 17

Drove to Kennecotts Ozark lead plant —
Harold Krueger Mgr — Ken Larson ch. geol.
18' dia concrete lined shaft — down into granite —
± 1500' — ore body ± 4½% Pb ~~[illegible]~~ < 1% Zn —
± 500' wide — ± 50' Thick — lower in the section
than WF — galena mainly in stringers along bedding
varying from ¼" up to 6" — some stringers converge
brown dol host with "fingers" or reef algae
(plant life) transloader haulage — 3 man team
~~to~~ drill, blast and haul up to 400 tpd per shift
(200 — 300 on development — 26' x 15' some
stopes 25' high — some roof bolting — leave
15% in pillars (ultimately) mine ± 4000 tpd — 7 days
per week — expect to go to 5 days alternately
at 1000 tpd — ship to Glover —
~~[illegible]~~ Break 10' rounds —
pump 700 gpm — ore trend, NW
Mar 18 — wed.

Drove from Sikeston, Mo. to Lebanon Tenn —
Discussed mid tenn. project with Del Harper, Jeff. Burton,
max Van G. — NJ prop ± 60 mi along NE —
ASARCO holes spotted around perimeter — 80-100% dol.
approx coincides with NJ prop with Elmwood deposit in
middle — Reviewed map of Kentucky project (north
of mid T project — also N Indiana — some
indications of interchange with some cuttings showing
sphalerite — Jeff showed contour maps of mid Ord.
in mid T area indicating possible ore in structural
highs — checked contact of dol & ls drill cores

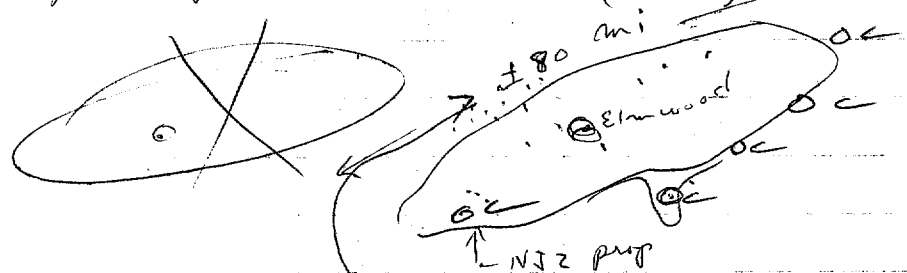
some Sph in calcite in bx in dol – also fluorite + barite in other bx — ls – dirty non xline appearance – prin dol – dense fine gr – second dol – csr xline.

Discussed Cu mo in Piedmont – few outcrops – deep saprolitic weathering of folded PreCambrian rks

Mar 19 – Thurs

Lebanon lab – reviewed core – st fl + barite calcite in bx (crackle bx) zone with minor sph – also sph in bx zone without fl-barite – Selected specimens – reviewed section about 200 miles long trending from So of Nashville into Central Kentucky. ± 10 Asarco holes – mid Dev ls – underlain by Knox – holes penetrate ≠ 400' of Mascot dolomite then stopped in Kingsport ± 100' below contact. Kingsp. is ls on SW but dol elsewhere – in Tenn – holes show transition going NNE from barren mascot dol to scattered fluorite – bar – with minor sph – to sph. Mascot thins going NE to near zero – caused by erosion on unconf. at top of Knox –

Reviewed plans for next holes – (4 rigs → 2 shifts)



Drove to Elmwood – considerable relief, heavy wooded hills – NJZ shaft down ≠ 1000' – saw one drill –

NJZ offered joint venture — their holes show strong fl + bar – minor sph – probably NW of sph zone

Mar 20 —

Drove to Knoxville office — reviewed gold + copper

Gold Hill > prospects in N.C. — Buffalo Creek area, Cabarrus Co. — 100 ppm Cu anomalies over 1 mile x ½ mi. in weathered greenstone along Buffalo flt between Charlotte intrusive belt and slate belt — in Appalachains — deep saprolite weathering — recon analysis for Mo, Ag, Au, Pb, Zn, Ni — no evidence of true veins in weathered rock — vein like manganese iron wisps — some possible sul boxwk —

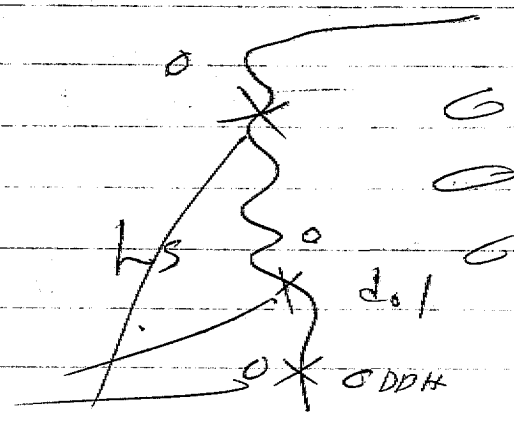
Bear Cr drilled Cu-Mo anom nearby near ring structure — Disseminated in granite

Various Cu-Mo shows along granite-dio intrusions of Paleoz age —

considerable strm sed work with some follow up soil sampling along Charlotte Slate contact —

Maine — numerous granitoid intrusions reported containing Cu and Mo — more research needed — to select most favorable areas for prospecting

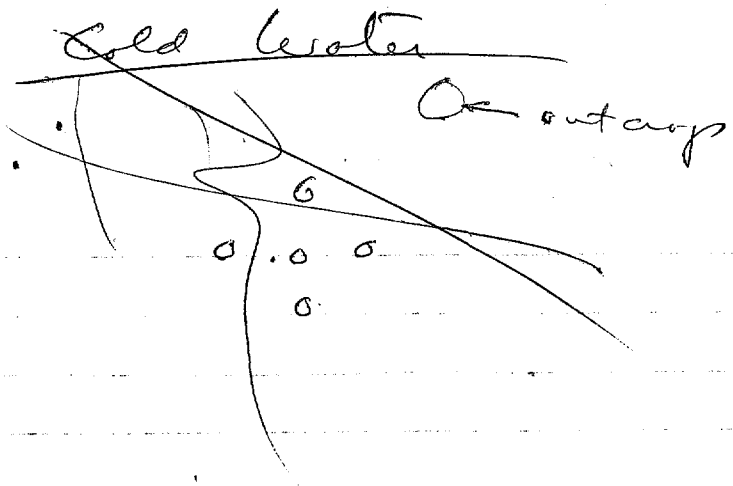
Delaware SE Mo.

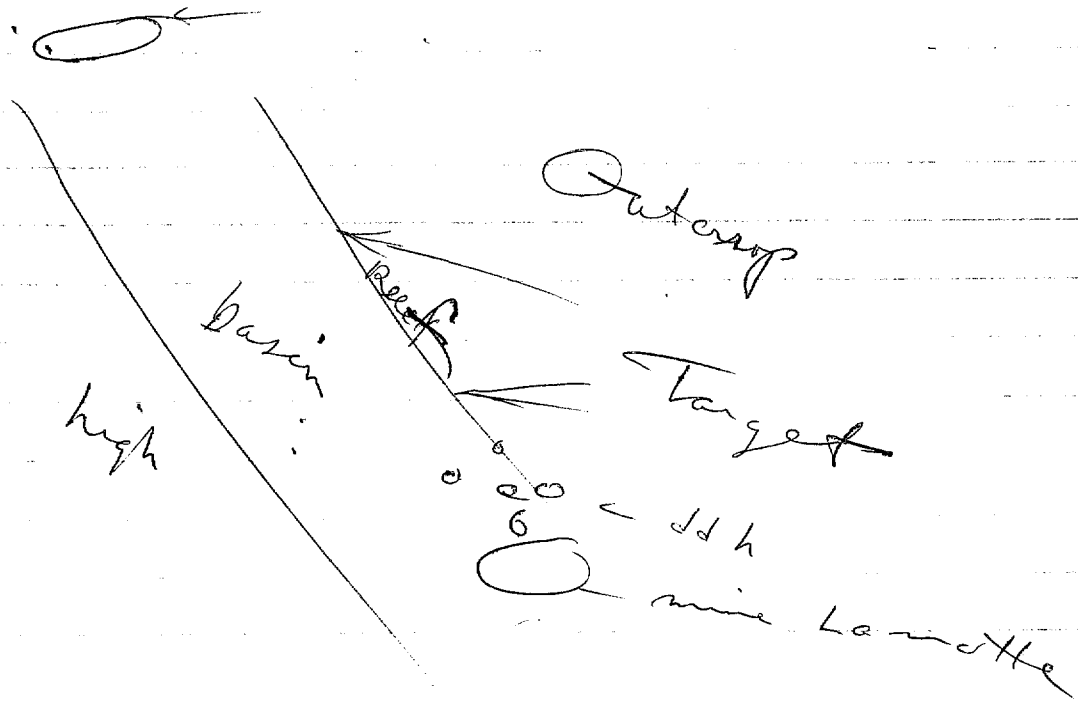


← Eminence outcrops

proposed holes

220,000 auth —





Holston hills area

(✓ oldest mine Mar 21

Drove to Mascot (Cu Zn) small open cut mines in early days - continuous mining since 1912 now 5000 tpd — next new Market, going Jeff city mine 3 miles each way from a shaft - translade then rail haulage to shaft —

Sell crush lime rock for road ballast tailings for soil conditioning (soil is acid) These by products sell for 1.00 — 1.25 per ton

average Zn — 3% — total tonnage from belt now 12000 tpd — S Africa

Cu Zn 7 09 held by Goldfields

NY city

Mar 21 (Cont.)

Bill, mrs Pollock.

Drove with John and Bea to Clem and Helen's home in Conn. Paul and Dotty? Harrison, Doug and Patsy
VP Industrial Relations + Personnel VP — VP — Sec + Gen Counsel
Soular, Frank Merwin + — A.J. Gillespie Jr. Bob + Lois
asst Controller
Kupsch, Bob + Richter — mrs Charles Barber
Ed + — Scheick.

Spokane - April 20 '70

Spokane off - Old V B. & whiting - SVF
Little B. Creek - cost 40,000 ecological studies - ± holes support

Goat Cr. second hole down 1873' - (1st 2050) - no - prect ale in veinlets or joints in meta seds - no diss. - eye estimates high - selected core runs - ± .10 MoS_2 occ .5 to 1.0% - 3rd hole - (incl) planned

Immigrant Cr. - Outcrop sampling - .17 MoS_2 - kidney shaped area rhy and latite (ext?) - with mp in tuffs in plug - Amax drilled 2 holes, to west - complex prop. set. - negoc. in progress (L & W)
Sunnyside Mine, Valley Co. Idaho - North of Yellow Pine - manto(?) in volc - 2 mil at 4.5 oz Au - limits partially defined by CD holes.

Conjecture Bonner Co. Ida. 5 to E of Sand Lake - Pandorielle
Duval Drilled - incl a 4000' hole - 3-4' wide veins - 10-15 oz Ag up to 40 oz - 2500' developed on strike - sat level (2000) in arg qzt transition zone (St Regis - Revett) - vein may have Revett on both walls at 3000' (located ± 50 mi E of CDA)

NW Montana - USGS map release - SLC studying data - photos
Cu in Belt series beds up to 15' - .8% Cu west of Helena
bleached areas in red argillite show on color photos - 3 or more occurrences - one area mapped in some detail - SVF states Bear Cr - has been studying for past 2 yrs -

Bay Horse west of Challis - Ag Pb veins & repl in ls
Dewey wheeler, Umont, SLC, promoter
ASARCO drilled in 40's

Middle Forks Cu prospect - King Co. Wn. (A.P. Grant, geol)
Possible 1.5 m at .7 Cu - in 6 x zones - some Mo

over

Middle Fk – cont

NE trending zone 4-5 mile long along Middle Fk
"Tectonic and replacement ox"
Condor – 1.6 m at .5 with 50¢ Ag
Bear Cr. quit in '65 – 36000' drilling incl other compain
Anaconda explored in '57-'60(?) called United Cascade

Petty Copper Prospect, Waterloo, Mont. Madison Co.
West slope of (North) Tobacco Root Mts.,
4 mi SW of Silver Bow Co. line –
Cu (ni, Cr by spec) in Pony Metamorphics – Proc – also
Cambrian – Qm (K or T) intrusive –
main interest has been in veins – but dis mn reported
mainly oxides + silicates plus some py, cpy at or near
surface – outcrop samples but veins – .02 – .10 Cu
Zone of oxidation measured 200 – 400' deep
Cu present 9.8 claims – zone of alt 1700 x 3000'
Wayne E Fowler + Assoc
Dolbear + Co, New Orleans

Q+S, Wn – Examined by Gale 1965
Rebecca " " " " "

SVF copied notes by Stevenson(?)
↳ will follow up this summer – assisted by NW geol.

Russel Smith – on vacation
Peterson – prospect for state H – work this season
has 3 boys lined up for summer

Wallace

Norm Kesten
Stan Huff
Dave Suhr — Galena — 5 yr
Jo Luchini — " — 1 yr
Enrique Gomez — " — de Mexico - (& Parral)
Phil Whitson — " (new)
Gene Callahan — Cover — 5 yr
Andy Rueda — will transfer to Van Stone
Steve Showalter — " " " Leadville
(2 yr with Anacon. at Butte)

Thurs 23rd '70

With Stan H. Enrique + Gene — to 2800, 31 + 34 Cover — near end of so drift (± 1000' from shaft) transition zone St Regis - Revett — beds dip steeply 75°-85° N veins dip S — ± 70° — principal vein (356) explored along strike ± 1000' — ore ± 500' — reserves 180,000 T — 17-18 oz — 5'-6' mining width — veins generally narrow (± 2') poorly defined — sid gangue varied pyrite — vein often parallel, or nearly so, to beds — this will cause more dil — in part veins cut across at up to 30° — others 400 + 425 also 353 (N-S) less Pb-Zn on 34 — expect improved grade + (thickness?) on 37 — (expect to be driving on 37 in ± 6 mo.)

Starting 34 N W to go around A m S — have hit vein striking toward Am S — plan no work — pending settlement —

Expl with 400' of Gal on 3100 — have not yet hit good vein develop on Galena side —

More arg in revett in Cover — drilling 4' diam raises for vent (rotary)

Polaris fault south of ore in Cover — no. of in Gal Anticline plunges E SE — Revett deeper in Val (Caladay) and Sil B ?) but St Regis outcrops in Rock Cr area —

~~Sou~~ So. R Cr may be best bet — Stan H thinks — more Polaris type struct may "spur off" SE — 356 pounds to west — values drop off to E —

Silver Summit — drove 3 miles on equiv of 34 (or 31)

Galena No 3 will go to 4900 — (developing on 4300 Silver vein lower in value —

Cover — 4130 bottom —

Galena Reserves 1,700,000 at 22 oz

Brackman 10 oz — incl develop —
Mill cap 800 — milling 600
Recov 97% — Geo. Deshler

Ward Cover Supt —
Rock Bolt 3 in iron sheet — 7 sheets per 7' round

DD holes — up to 1100' —
Contract 606 up — an overall cost 10.00 per ft.

Monday May 18, 1970

Vancouver office –
Tom O. J Deleen – Sal Anzalone – brief review of Emery, Chalaway, Griswold, Tet – Vancouver Island – Dawson range – Eliz mdy pni top (Willson) low no – mod cu rock chip sample – (Alaska)
Stella – secretary Sturgeon L area 1965 E.M Targets
Hope landslide

Tues – May 19 –

Left Van 11:10 – drove thru Hope – stopped at Ingerbelle NW of Cop Mt. – saw old rd cut – orig sampling 100' of 1% Cu – cu stain + diss cpy – bn in silic – sltly sericitized volcanics? some iron staining – some py – some pink feld? – scratches – may be zeolite – zone ± 300' wide ± .5 cu Newmont have cleared timber for open pit – best cu in gray to greenish gray dense silic rk – ± 50 mod open pit – zone continues at depth –

Drove thru Princeton, Aspen Grove to Merritt – Grasslands Hotel – TCO – no rpt on Little Bowl Creek poss. ? mine 10-20 mill at .2 –

Wed – 20

Emery Bayley picked us up at 7:30 – drove past Craigmont up to Lower Vimy – narrow (± 50') shear zone with cpy – bn – cu stain in alt grd – mainly in qtz stringers – Upper Vimy: zone of mod st ser in grd – diss cu – limits not visible in open cut, but 5 holes on EW line define zone ± 200' wide – st NW dip NE – ± .2 – best .3 cu Zone 4 – sp cu in trenches – zone? por dike – Jay 11 – v sp cu in trenches – 3 creeks v sp cu in punky brown alt – The latter noted in several areas – dinner at camp Dot lake – returned Merritt saw beaver waddling down road – saw moose earlier in day ——

Thurs May 21

Drove to Bethlehem via Spences Bridge —
Brief chk of Hunter's pit (stripping just started)
Cu stain in Beth phase — ± .5 cu — mainly oxide
Toured south high up bench of Jersey — examined Beth phase,
Guichon qdio and por dike + ~~E~~ int bx — v sp cu —
To Lornex — small pit (for pilot mill) — sheared
zones — parallel joints — with cpy-bn-cc — cu so4 — plus oxides —
alternate with less alt, less mineg Beth side phase
50 mil per mine — ± 60' oxide — ± 1:1 strip —
overb ± 200' deep on west side of "Lornex fault" —
v sp py → Strong ser in better cu zones — Mike Skopos — geol.
To Valley Cop — Jim Allen — geol — down
decline ± 300' to x cut — pervasive ser — in Beth side
stockwk of min joints and qtz veins — arg ill alt
with chloritic alt between stk wk — ~~Gous~~ Beth side
has large sq mica bks — long qtz anhed phen ox —
Core outside zone v wk alt ~~no~~ v little chl —
almost no py in ore, ~~non~~ no halo — pink second ortho
close up iquitous — ~~p~~ ore extend ± 1000' southerly
under slope — min 10' over burden — deepens and
valley to ± 400' (?) — high gesch cu uphill — down
slope ± 100 ppm — back gr — 30, IP 2 & 3 x back gr
Returned to Merritt — Sal Tom + John to Vane
— with Emery to Chataway — Thateway — ice gone on
Dot lake —

May 22

With Emery to Gypsum Lake showings — Trace cu —
no pervasive alt — continued on thru zone 4 — spotted 2
holes in upper Vinny — 100 + 200 west of No 7 (?)
PM — SW to Sho 11 — Then to Moss 4 area — long deep
trenches — ~~sm~~ ~~cu~~ sp bedrock showings — some iron st.
rock — v wk alt — some cu + st alt but apparently
confined to narrow zones — numerous aplitic dikes
in northern trench.

Sat May 23

Inspected trenches on south near boundary of prop — some diss cu — scattered blobs in slt alt grd — trench full of water PM — to old Chataway "mine" — narrow stringers cu in shaft but fr grd — checked outcrops further n —

Sun 24

Checked outcrops on s below prop — deep canyon — extensive trenching — minor cu in shear zones located ± 5000' NW of Aberdeen "Mine" — deep erosion Broom Cr. in this area has exposed barren bedrock in many places — no chance that important zones of min exist.

2" percussion drilling — 2.75 per ft. (gardner D drill — Joy compressor — drill ± 80' into bedrock — 1/4 th split taken — volume measurement recorded — Average ± 200' per shift. T-25 (int Harv) 30.00 per hr.

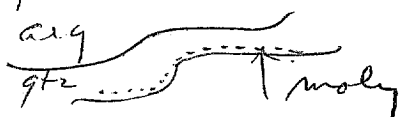
Monday 25

Emery reported by radio phone — hit cu in hole in cover area SE of Lower vinny — BR at 40' — cu to 100' on open fraction — which will be pegged.

Monday — inspected core from Goat Cr —

Tues June 23 - 1980

With KW - Bill S, Russ Smith from Spok Thru Burke to Thompson Falls — lunch — Then to Goat Creek prospect — argillite (Wallace) varies from flinty to med hard — slight scratch — med to strong meta — central zone 1000 x 150 st NW — shows best limonite + qtz veining (in road cuts — mainly float very few bed rock exposures) — only 2-3' of soil mantle some py at surface — very sp mo and O chre — no diss or discrete grains — py in blebs + ~~vein~~ along with qtz veins —



No 3 incline hole 12-3 mo 5, 1400 to 1520
(hole bottom) -

Contact NX hole 950 to 500 - 975 1000
± 40' - 10 hr shift - (2 shifts) —
50-100' per bit — water circ —
July 22 big - Boyles —

No 1 hole in best fox exposure —
elev 4500-5000 —
Drove to Missoula - Holiday Inn —

July 24

Aug a - see att yellow sheet Russ Smith
Emigrant Creek Prospect - mapped by July 25
From Livingston along Yellowstone river then
up Emigrant Cr. to poly prospect —
Drove up 4 miles above Chico Guest Ranch —
waited for horses - then 4 miles up canyon
high water - "raging torrent" - road washed
out in places - sp Mo, cu (py) in dense,
~~sil~~ flinty porphyritic volcanics - flow banding
feld spar phenocrys dips NE ± 60° - intrusive rhy or latite.
mo cu ~~py~~ associates with qtz veinlets and joints
min widespread, but obviously average under .05% mo
and cu - py ubiquitous - breccia pipes widely other
(no intermingled intrusive por) contain conc mo (± 40)
but no cu - much py - ~~Will~~ over all up to ~~8~~ 10 ppm Ag
or ~~as~~ 3 ppm - Wallace no assay - erroneously high
± 100 samples - plus chk sam taken in field -

paleoz sed and precam gneiss near mouth - at Chico Hot Springs

Intrusive dikes - med gr mp - sp alt some
recryst - some dis cu and mo -

Bx zone in canyon bottom st py - plus pb zn?
reddish pyritic zones to west - drilled (one hole) by Cimarex
Dark volcanics in canyon - show some sp as agg -

Sat June 27 – 1970

Copper King – west of Cheyenne

to office in Cheyenne – examined core – DDH – A-6-7-8
A-6 – sp oxide – principally chrys + Cu pitch – BR at 40'
hole bot ±150 –
A-7 Cu OX to ± 100' – then cpy as minute discrete grains
and stringers – discontinuous – in porphyritic granite
(Pre-Є) – ± 400' Cu – .06 Au – bot in
log.
A-8. Cu OX (ox, sil + native) to ± 100' – Then
fair cpy to ± 400, from 400 to 500 (bot) ± .05 Cu
± .6 Cu – .08(?) Au

Cu invariably associated with qtz (as veins or layers
in foliated qp or met seds (Pre-Є complex) or as
fine granular silica flooding – very minor py, less
than 1:1, py : cpy – little or no visible hydr th alt
of por Cop typ – react gange – feldsp-bio-hnblende
essentially no migration of copper – in oxide zone
or Cu is only part of orig Cu – small cpy grains +
tiny stringers have oxidized + leached leaving no visible
cast or visible Fe ox – Cu dispersed – adsorbed in matrix
as oxide? Large grains + stringers show some resid bx w/ K
CuSil – pitch –
Drove to deposit – one drill op 1 shift –
A-6 in alluvium – A-7 + A-8 in outcrop – much Cu sil, qtz
veins (very rare) and silica in pr Gr – transport west
occ outcrop and prospect pit – weakly min – occ
Cu stain – some pink feldspathic rock – some
foliated – Pre-Є complex – over area of inclined
drill hole – further west in canyon bottom filled
adit – trended east to end of some – sil + min
appear to diminish – old incline shaft shows 2-3 Cu
over ±500' – possibility appears best to east
out crop pits show Cu stain – some appear to pinch to Cu –

Tues - July 14, 1970

With Sal, Larry Applegate, JDS & prospect N of TOK
Hiller 3 passenger chopper ferried us up to mountain
top ≠ 3500 elev - heavy moss and brush cover but
a few outcrops - some sliderock on steep north slopes
Some Rain — pyritic zone has retarded vegetation —
as mapped by Larry, zone is ≠ 2500 x 4000' —
med grain to fine granular qtz por — fine gr
facies appear volcanic (ash?) — less alt granodi.
on fringes — in general alt is argillic with
jarosite and brown limonite in casts — some sericitic
alt along fractures with darker limonite, but
fracs. are very wide spaced — sericite prominent
in sizeable area on west in coarse grained qtz feld
chlorite rock — in places silicified — occ
darker limonite — occ remnants of pyrite
in yellow brown limonite — pyrite only
in canyon on north — along with jarosite.

Concl: sizeable zone of pervasive alt in
probable Laramide intrusive complex — occ
py remnants suggest leaching is superficial
(average 3-5% sul content) zone probably
pyritic with only minor Cu — slim chance
of economic deposit — but may be worth a
hole or two if rock geochem results are
encouraging.

Check drainage ≠ 1 mile to north along hwy
— found altered pebbles —

Wed - July 15, 1970

Rain
Snow
cold
wind

To Ptarmigan Co camp near junction - by chopper to Eliz prospect - 5000' elev - 6 ASARCO holes in zone ± 1000' wide 2000' long - elongated northerly - strong argillic alt in alaskitic rock - local st ser + silic f. - moly on q. stringers only - local str q veining but rather sparse over all - abundant talus, but no outcrops of altered rock - prom outcrops of fresh, dark (andesitic) dike rock - port mineral incl holes on south + E - cors indicate penetration of alt zone (all collared in talus) but may not have tested best part (upper central part). TDS - proposes that zone is wider than mapped - particularly on west where alt frags are mingled with barren and in moss covered soil - this is possible - but likely a fingering out situation -

leaching very superficial - some py - perhaps 3 - 5 g - a fair idea of grade could be obtained from pits in talus along crest (one pit in outcrop) - although some moly no doubt leached out -

checked core in No 6 - went from alt rock into Barren and ± 200' - alt-silic in 3 + 4 - check file in Van -

At Ptarmigan camp met Howard Gray - geologist Sal + I by chopper to Orange Hill - landed at edge of Nabesna glacier - qtz filled fract in diorite and also in schist - no alt - occ cpy st py in orange hill - some Tactite in cliff above - rotary drilling in spotty alt area below tactite - 15 cu ft in Orange hill - sp mo. - no laramide por noted any where - even in gravel. -

Returned to Tok - saw mt sheep + moose enroute

June 12 58

1. Left Lordsburg 6:00 AM – drove to White Signal with KR. check outcrops ± 1 mile SE W.S. station moderate alteration in alaskite (Pre Camb gr.?) with some evidence of diss. suls – but limonite (in small vugs & rare veins) appears to be after spec. – some spec showing in narrow veinlets.

2. Met Blucher on highway and checked area along south side of highway 1 to 2 miles west of White Signal – extensive zone of alteration in alaskite – locally shows mineralized shears quite close spaced – but limonite seems to be mainly after spec – some spec showing in veins ± ½ inch thick

3. Drove to Silver City – checked in at Murray Hotel. Then to Hanover – took left hand road up NW trending gulch just south of Fierro. Noted alteration in diorite por and in Colorado shale in vicinity of Baringer fault. Continued northwesterly to saddle. Noted diamond drill hole inclined under small area of alteration showing some green copper on south slope of knoll capped by basaltic flow breccia (post Mineral) Continued westerly to SW for 3 or 4 miles and examined "andesitic breccias" considered to be ~~late Tert.~~ Late Cret. or early Tert. – these breccias resemble!

Silver Bell cg. — were resting on a basal cg. of well rounded pebbles which in turn rested on gentle westerly dipping Col. Sh. — They are mapped as older than the porph. intrusives — and appear to be so (the Silver Bell type)

June 13 '58

Recon north of Santa Rita — checked small areas of porphyry sticking out from under the post mineral cover on the north — alluvium appears to fade out south of the cover — noted several large dumps a short distance north of Fierro — this hill mapped as Colo. but dumps contained some por with strong dis cpy-cc. some lime limonite in float — but apparently the dis copper is confined to small vein zones or the narrow por dikes — this adit expl. probably conducted during porphyry copper boom of 1910 or 1915 —

Blucher made sketch of breccia pipe NW of Fierro — about ½ by 1 mile in diam. — found USSR Co. drill holes — some Pb in bx — but in general appears weakly mineralized

Breccia shows unusually tight texture — composed of — mainly Colo. sh. — some porp — Pipe is elongated northerly — may extend under basalt flow bx —

PM — Ken started back for Tucson — Blucher & I drove thru Deming, Las Cruces & Almagordo.

Sat. June 14, 58

Left Almagordo 6:00 AM — drove to Carrizozo — then east 8 miles — then south thru Nogal and up Bonita creek 9 miles to Parson mine — 12" fractures growing in open cut — some minutiae bx texture in walls — host rock mainly andesite (flow) — some porp may be intrusive — NE adit shows limits — no sulphide seen — alteration is strong but argillic — zone appears to be a mile or more in extent — (a few flecks of blue green Cu in open cut.)

Similar alt in Hopefull mine area —

checked float along road east of Nogal PK nothing other than pale tan to brownish argillic alt in flow rocks — some outcrops — showed spotty alt.

Drove back to highway — then 2 miles east to gate — then 1½ miles south along old rd to Vera Cruz mine — about 1000 ft on SW slope of — into found bx pipe in flat lying shales & SS — a few frags of porp — pipe about 200 wide at NE end (open cut) appears to taper and terminate at old mill ± 700' SW — bx strongly alt — occ vug of fine limonite — but most of bx is yellowish (pale brown) — appears to have been weakly pyritized (with Au values) took small sample & specimens for check on radioactivity —

Drove North of Carrizozo 4 miles then N easterly to White Oaks dist — ~~the~~ gravels in gulches show considerable pale yellow bleached andesite & shale — a number of vein prospects — with similar alt. but no intrusions seen other — or andesite dikes —

Drove on North and NW to Ticaril Dist — numerous small vein prospects more or less typ mnz por — showing oxid, very weak alt — no evidence of copper, although area not well covered — little or no production apparently, but some very live and hostile claim holders still present

Stayed in Carrizozo —

June 15

Left Carrizozo 7:00 AM - drove to Corrillos - south to Golden - noted coal mines in Cret? beds at Madrid enroute. Returned to Corrillos, then south to Delores (± 7 miles) on N to E side of Ortiz Mts. met O.F. Genn cattle Rancher (selling feeders at 32) - said Potters & Simmons hold Cunningham Hill by claim loc. - they conducted extensive DD and surface sampling program in 1952 (?) - several vert holes 1200' deep - some lower angle holes. Extensive area of dry placer east of Delores. - main showings consist of a breccia pipe ± 1000' by 600 - elongated NE - Brecc outcrops - oxidized consist of fragments of arkosic SS & shale (1" to 6" dia - some 4 ÷ 5' foot angular pieces - country rock is sed - some por - occ. por in bx - st argillic alt in bx.

noted several DD locations — also some workings that reached sulphides. [illegible] ex certain pyrite — ± 5% to 10% of rock — outcrops show much specularite & limonite after spec — some partially ox specimen suggest that formed after Py — no primary Cu

Drilling & sampling appears to have been thorough.

Drove North to Cerrillos — Rio Grande — then to Bland adits in alt por (argillic) ovr in crumbles tuffs — did not definitely locate v. l.

continued northerly to ± 9000 ft elev, not road — then easterly to Rio grande — passing round to Los Alamos mnts — noted common tuff — very extensive — good for owls & bats — overlying basalt rubble — stopped in Motel at Espanola at 7:15 PM